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Unmanned Aerial Vehicle End-to-End Support Considerations

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Preface

Unmanned aerial vehicles (UAVs) have seen successful employment in recent operations, such as Operation Enduring Freedom and Operation Iraqi Freedom. These successes have confirmed the military utility of UAVs and portend that a greater number of such vehicles may become part of the Department of Defense's (DoD's) future force posture. However, because of the acquisition strategy employed to get these UAVs into the field as quickly as possible, the implications for their long-term support needs are unclear.

This report presents the results of an analysis of end-to-end support options for UAVs. The analysis concentrates on current support postures and evaluates methods for improving current postures that may also be applied to future systems.

The Air Force Deputy Chief of Staff for Installations and Logistics (AF/IL) sponsored this research, which was conducted in the Resource Management Program of RAND Project AIR FORCE, in coordination with the Air Force Deputy Chief of Staff for Operations and Requirements (AF/XOR) and the office of the Secretary of the Air Force, Acquisitions (SAF/AQ). The research for this report was completed in September 2004.

This report should be of interest to logisticians and operators throughout DoD, especially those in the Air Force.

This report is one of a series of RAND reports that address agile combat support issues in implementing the air and space expeditionary force (AEF). Other publications issued as part of the larger project include the following:

- *Supporting Expeditionary Aerospace Forces: An Integrated Strategic Agile Combat Support Planning Framework*, Robert S. Tripp et al. (MR-1056-AF), describes an integrated combat support planning framework that may be used to evaluate support options on a continuing basis, particularly as technology, force structure, and threats change. (1999)
- *Supporting Expeditionary Aerospace Forces: New Agile Combat Support Postures*, Lionel Galway et al. (MR-1075-AF), describes how alternative resourcing of forward operating locations can support employment timelines for future AEF operations. It finds that rapid employment for combat requires some prepositioning of resources at forward operating locations. (1999)
- *Supporting Expeditionary Aerospace Forces: An Analysis of F-15 Avionics Options*, Eric Peltz et al. (MR-1174-AF), examines alternatives for meeting F-15 avionics maintenance requirements across a range of likely scenarios. The authors evaluate investments for new F-15 Avionics Intermediate Shop test equipment against several support options, including deploying maintenance capabilities with units, performing maintenance at forward support locations (FSLs), or performing all maintenance at the home station for deploying units.
- *Supporting Expeditionary Aerospace Forces: A Concept for Evolving to the Agile Combat Support/Mobility System of the Future*, Robert S. Tripp et al. (MR-1179-AF), describes the vision for the agile combat support (ACS) system of the future based on individual commodity study results.
- *Supporting Expeditionary Aerospace Forces: Expanded Analysis of LANTIRN Options*, Amatzia Feinberg et al. (MR-1225-AF), examines alternatives for meeting Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) support requirements for AEF operations. The authors evaluate investments for new LANTIRN test equipment against several support options, including deploying maintenance capabilities with units, performing maintenance at FSLs, or performing all maintenance at support hubs in the continental United States for deploying units.

- *Supporting Expeditionary Aerospace Forces: Lessons from the Air War over Serbia*, Amatzia Feinberg et al. (MR-1263-AF, not available to the general public), describes how the Air Force's ad hoc implementation of many elements of an expeditionary ACS structure to support the air war over Serbia. Operations in Serbia offered opportunities to assess how well these elements actually supported combat operations and what the results imply for the configuration of the Air Force ACS structure. The findings support the efficacy of the emerging expeditionary ACS structural framework and the associated but still-evolving Air Force support strategies.
- *Supporting Expeditionary Aerospace Forces: Alternatives for Jet Engine Intermediate Maintenance*, Mahyar A. Amouzegar et al. (MR-1431-AF) evaluates the manner in which jet engine intermediate maintenance (JEIM) shops can best be configured to facilitate overseas deployments. The authors examine a number of JEIM supports options, which are distinguished primarily by the degree to which JEIM support is centralized or decentralized. (2001) See also Engine Maintenance Systems Evaluation (En Masse): A User's Guide, Amouzegar and Galway (MR-1614-AF).
- *Supporting Expeditionary Aerospace Forces: Forward Support Location Options*, Tom LaTourrette et al. (MR-1497-AF, not available to the general public).
- *A Combat Support Command and Control Architecture for Supporting the Expeditionary Aerospace Force*, James Leftwich et al. (MR-1536-AF), outlines the framework for evaluating options for combat support execution planning and control. The analysis describes the combat support command and control operational architecture as it is now and as it should be in the future. It also describes the changes that must take place to achieve that future state.
- *Reconfiguring Footprint to Speed Expeditionary Aerospace Forces Deployment*, Lionel A. Galway et al. (MR-1625-AF), develops an analysis framework—as a footprint configuration—to assist in devising and evaluating strategies for footprint reduction. The

authors attempt to define footprint and to establish a way to monitor its reduction.

- *Analysis of Maintenance Forward Support Location Operations*, Amanda Geller et al. (MG-151-AF), discusses the conceptual development and recent implementation of maintenance FSLs (also known as centralized intermediate repair facilities) for the U.S. Air Force. The analysis focuses on the years leading up to and including the AF/IL centralized intermediate repair facilities test, which examined the operations of centralized intermediate repair facilities in the European theater from September 2001 to February 2002.
- *Supporting Air and Space Expeditionary Forces: Lessons from Operation Enduring Freedom*, Robert S. Tripp et al. (MR-1819-AF), describes the expeditionary ACS experiences during the war in Afghanistan and compares these experiences with those associated with Joint Task Force Nobel Anvil, the air war over Serbia. This report analyzes how ACS concepts were implemented, compares current experiences to determine similarities and unique practices, and indicates how well the ACS framework performed during these contingency operations. From this analysis, the ACS framework may be updated to better support the AEF concept.
- *Supporting Air and Space Expeditionary Forces: A Methodology for Determining Air Force Deployment Requirements*, Don Snyder and Patrick Mills (MG-176-AF), outlines a methodology for determining manpower and equipment deployment requirements for a capabilities-based planning posture. A prototype research tool—the Strategic Tool for the Analysis of Required Transportation—generates lists of capability units (unit type codes), which are required to support a user-specified operation.
- *Supporting Air and Space Expeditionary Forces: Lessons from Operation Iraqi Freedom*, Kristin F. Lynch et al. (MG-193-AF), describes the expeditionary ACS experiences during the war in Iraq and compares these experiences with those associated with Joint Task Force Nobel Anvil, in Serbia, and Operation Enduring Freedom, in Afghanistan. This report analyzes how combat

support performed and how ACS concepts were implemented in Iraq and compares current experiences to determine similarities and unique practices, and indicates how well the ACS framework performed during these contingency operations.
- *Supporting Air and Space Expeditionary Forces: Analysis of Combat Support Basing Options*, Mahyar A. Amouzegar et al. (MG-261-AF), evaluates a set of global FSL basing and transportation options for storing war reserve materiel. The authors present an analytical framework that can be used to evaluate alternative FSL options. A central component of the authors' framework is an optimization model that allows a user to select the best mix of land- and sea-based FSLs for a given set of operational scenarios, thereby reducing costs while supporting a range of contingency operations.

RAND Project AIR FORCE

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Summary

Unmanned aerial vehicles (UAVs) have been used in combat operations since the mid-1900s (Office of the Secretary of Defense, 2002). More recently, both Operations Enduring Freedom and Iraqi Freedom have employed UAVs for intelligence, surveillance, and reconnaissance, as well as time-critical targeting. These successes have confirmed the military utility of UAVs and portend that a greater number of such vehicles may become part of the DoD's future force posture. However, because of the acquisition strategy employed to field UAVs as quickly as possible, the implications for their long-term support needs are unclear.

The Air Force originally acquired its Predator UAV, used in recent options, as an advanced concept technology demonstration (ACTD). While an ACTD makes it possible for an operational capability to reach a combatant commander quickly, it raises concerns about the mid- to long-term effects of not completing the traditional logistics requirements determination processes. Because of the rapid acquisition and accelerated production schedules for the current unmanned systems, there was not enough time to complete these processes—or to gather the data with which to do so. A method for bridging the gap between rapid acquisition and traditional processes for determining logistics requirements needs to be established.

This report provides the background and results of a review of Air Force UAV and, to the extent possible, unmanned combat aerial

vehicle (UCAV) support options.[1] The analysis concentrates on current support postures and evaluates methods for improving current postures that may also be applied to future systems. Operational issues, such as potential employment options, are not considered in this report unless specifically related to support requirements. This report is meant as a review of systems that the Air Force currently owns or is acquiring, not as a critique of what the Air Force has purchased. We review the acquisition process only in terms of identifying ways to aid future acquisitions. The Air Force Deputy Chief of Staff for Installations and Logistics (AF/IL) sponsored this research in coordination with the Air Force Directorate for Operational Requirements (AF/XOR) and the Office of the Assistant Secretary of the Air Force for Acquisitions (SAF/AQ).

After reviewing combat support postures and lessons learned data for various current UAV systems (Global Hawk, Predator, Pointer, Raven, FPASS, BATCAM, and UCAV), the team looked for commonality among vehicles, support equipment, and requirements and examined the lessons learned on the individual programs and the issues they faced that could assist with defining recommendations to shape future support decisions. The team found that rapid acquisition strategies lead to design and procurement issues and disconnects between the requirements determination process and the acquisition process (see pages 19–24).

Rushing advanced concept technology demonstration prototype vehicles into production leaves no time for completing the system development and demonstration (SDD) cycle.[2] SDD would allow support concerns to be addressed prior to production of the vehicle. Without an SDD, much of the type of data needed for determining logistics requirements is not available (see pages 19–21).

A balance must be struck between providing a new capability rapidly and the effects of that on long-term support of that capability.

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[1] At the time of this study, the UCAV was a Defense Advanced Research Projects Agency effort, and the Navy and Air Force had just submitted new operational requirements.

[2] SDD is the process formerly known as engineering and manufacturing development (EMD).

Traditional metrics normally associated with Air Force aircraft may not accurately depict the capabilities of a UAV system. For UAVs, a key metric in assessing the effectiveness of support and acquisition policies is the UAV fleet's ability to provide orbital coverage. To that end, the RAND Corporation developed a methodology for evaluating options for improved end-to-end combat support for UAVs (see pages 25–29). This methodology, which may be applied to both current and future systems, can be used to illustrate how logistics issues can affect operational capability. For this analysis, we applied the methodology to illustrate ways to improve UAV global support concepts to improve deployment and employment of current and future systems (see pages 29–36).

Even if the Air Force does not employ a methodology similar to the Logistics Implications Capabilities Assessment Model, there are several logistics support issues that the Air Force should address to enhance future UAV development. One example is budgeting to resolve support issues that arise during testing and evaluation. Future systems could build funding into the program budget for addressing test and evaluation support findings, thus improving air vehicle design and perhaps reducing long term support costs before the air vehicles enter full rate production (see page 37). Training issues need to be evaluated, and an integrated training requirement needs to be developed (see pages 41–42). Spiral development could also be addressed before production begins. If spiral development is used in future systems, having a plan in place to standardize the airframe before production begins could alleviate some logistical issues, such as maintaining multiple configurations of an air vehicle. Multiple aircraft configurations drive multiple spare component packages and, in the most extreme cases, may drive multiple pieces of test equipment, all significantly increasing long-term support costs (see pages 21–23). Additionally, a process should be initiated to ensure insights gained in current programs will be applied to future UAV acquisitions.

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Abbreviations

ACC	Air Combat Command
ACTD	advanced concept technology demonstration
AEF	air and space expeditionary force
AFB	air force base
AFI	Air Force Instruction
AFSOC	Air Force Special Operations Command
ASC	Aeronautical Systems Center
ASC/RAB	Big Safari Special Program Office
ASC/RGF	ASC Global Hawk Financial Management
ASC/RGL	ASC UAV Program Office–Global Hawk
BATCAM	Battlefield Air Targeting Camera Autonomous Micro–Air Vehicle
BDA	battle damage assessment
BLOS	beyond the line of sight
CDL	common data link
CGS	common ground station
CONOP	concept of operation
CONUS	continental United States
CS	control station
DARPA	Defense Advanced Research Projects Agency

DATMS	Defense Information Systems Network's Asynchronous Transfer Mode Service
DoD	Department of Defense
EO	electro-optical
FPASS	Force Protection Airfield Surveillance System
FSL	forward support location
FY	fiscal year
GCS	ground control station
GMTI	ground moving target indicator
GPS	Global Positioning System
HAE	high-altitude, long-endurance
IES	imagery exploitation site
IMINT	imagery intelligence
INMARSAT	International Maritime Satellite
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
JEIM	jet engine intermediate maintenance
JPO	Joint Program Office
J-UCAS	Joint Unmanned Combat Air System
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
LICAM	Logistics Implications Capabilities Assessment Model
LOS	line of sight
LRE	launch and recovery element
LRU	line-replaceable unit
LSA	logistics supportability analysis
MAE	Medium Altitude Endurance
MCE	mission control element

MP-RTIP	Multiplatform Radar Technology Insertion Program
MTOW	mean takeoff weight
MTS	Multispectral Targeting System
POM	program objective memorandum
SAB	Air Force Scientific Advisory Board
SAM	surface-to-air missile
SAR	synthetic-aperture radar
SATCOM	satellite communications
SEAD	suppression of enemy air defenses
SDD	system development and demonstration
SIGINT	signals intelligence
SORAP	source of repair assignment process
SPO	system program office
UAV	unmanned aerial vehicle
UCAV	Unmanned Combat Air Vehicle
USA	U.S. Army
USAF	U.S. Air Force
USMC	U.S. Marine Corps
USN	U.S. Navy

CHAPTER ONE

Introduction

Unmanned aerial vehicles (UAVs) have been used in combat operations since the mid-1900s. More recently, both Operations Enduring Freedom and Iraqi Freedom employed UAVs for intelligence, surveillance, and reconnaissance (ISR) and for time-critical targeting.

This report provides the background and results of a review of support options for Air Force UAVs and, to the extent possible, the Unmanned Combat Air Vehicle (UCAV). It does not address operational issues, such as potential employment options, unless they are specifically related to support requirements. Our objective was to review systems that the Air Force currently owns or is acquiring, not to critique its acquisition decisions. We reviewed the acquisition process only to identify ways to aid future acquisitions.

Study Motivation

The Air Force originally acquired its Predator UAV as an advanced concept technology demonstration (ACTD) and has employed it in recent operations. Before this acquisition, the Air Force had had very little experience with ACTDs. While an ACTD makes it possible for an operational capability to reach a combatant commander quickly, it raises concerns about the mid- to long-term effects of not completing the traditional logistics processes: a logistics supportability analysis (LSA) and/or a source of repair assignment process (SORAP).

Both LSAs and SORAPs are accepted Air Force processes to determine logistics requirements. Having little experience with the

ACTD process, the Air Force had concerns that this new and rapid acquisition process and the typical processes for determining logistics requirements did not mesh fully. Because of the rapid acquisition and accelerated production schedules for the current unmanned systems, there was not enough time to complete these processes—or the data with which to do so. This meant that the Air Force had to rely heavily on contractors to support these new systems in the early stages of these programs. It has also raised serious questions about how and whether the responsibility for support should transition to the Air Force. ACTDs have been used for acquisition a number of times over the last decade. A method for bridging the gap between rapid acquisition and traditional processes for determining logistics requirements needs to be established.

Although the Air Force has had great success in employing Predator, a structured requirement-review process would have been helpful. The budget did not include funding for reviewing requirements. In an effort to address system issues, the Air Force offered to delay purchasing some future air vehicles to allow using their funding to purchase maintainability and supportability enhancements. Despite agreeing on the need for these enhancements, Congress directed the Air Force to make the acquisitions as planned. Therefore, no money was available for a formal review of system support requirements.

In addition to the Predator, numerous other UAVs are currently being acquired. Some are extensions of classified programs for which the overall cost of support is not a primary consideration or of programs for which the vehicle's life expectancy is short, thus requiring little support. Others are new programs aimed at providing new capabilities. The U.S. Army, Navy, and other branches of government, as well as foreign interests, all have UAVs in their air fleet inventories, and these force structures are expanding.

Recent successful operational deployments of UAVs, the increased capabilities they provide, and the rapid acquisition used for them were the primary motivations for this study. This report will address these and other concerns that arose during our review of the current UAV support posture.

Analytic Approach

This report presents the results of an analysis of end-to-end support options for UAVs. We concentrated on current support postures and evaluated possible improvements that might apply to future systems.

The first step was to gather and review combat-support postures for various current UAV systems. We therefore gathered information on Global Hawk, Predator, Pointer, Raven, the Force Protection Airfield Surveillance System (FPASS), the Battlefield Air Targeting Camera Autonomous Micro (BATCAM) air vehicle, and UCAV. We also gathered information on future UAVs. Information was obtained by visiting operating agencies, test and evaluation facilities, depots, and manufacturing facilities. We met with functional representatives at the major commands and in the system program offices (SPOs) at Air Force Materiel Command. Predator information came from Indian Springs Air Force Station, Nevada; the Air Combat Command's (ACC's) Big Safari SPO; the 645th Materiel Squadron, Detachment 3; and General Atomics. Global Hawk information came from ACC; the Aeronautical Systems Center's (ASC's) UAV Program Office for Global Hawk (ASC/RGL); and 31st Test and Evaluation Squadron at Edwards Air Force Base (AFB), California. The Air Force Special Operations Command (AFSOC) provided information on Pointer and Raven. Electronic Systems Command provided the data on FPASS. We also gained insights into future UAV operations by reviewing the Air Force Scientific Advisory Board reports and the work of our RAND colleagues, through conversations with the UAV Battlelab, and by attending the annual conference of the Association for Unmanned Vehicle Systems International.

The team gained further insights on UAV operations and potential future operations from the Department of Defense's (DoD's) UAV Roadmap, the Air Force Transformation Flight Plan, the Air Force Posture 2004, several reports from what is now the Government Accountability Office and from the Air Force Scientific Advisory Board on UAVs and on command and control, and the ACC concepts of operation (CONOPs) for both Predator and Global Hawk. From employment and peacetime CONOPs, we gleaned

vehicle instructions, mission performance data, and training and exercise requirements. Finally, we reviewed data on lessons learned during deployments and peacetime training and test operations.

The team looked for commonality among vehicles, support equipment, and requirements, as well as in the lessons learned or the issues individual programs faced that could help us define recommendations for shaping future support decisions. These reviews of ACTD issues and rapid acquisition processes have enabled us to suggest improvements in support for both the current and future systems (Thirtle, 1997; Drezner and Leonard, 2002c).

RAND then developed a methodology for evaluating options for improving end-to-end combat support for UAVs. This methodology, which may be applied to both current and future systems, can be used to illustrate how logistics issues can affect operational capability. In this report, we apply the methodology to illustrate ways to improve UAV global support concepts to improve deployment and employment of current and future systems.

Finally, the team reviewed and evaluated costs for providing end-to-end combat support for UAV systems. In our analysis, we compared contractor support to organic support. We also highlighted other support issues that may affect future UAV systems, such as test and evaluation funding and spiral development processes.

Organization of This Report

Chapter Two examines the features of several UAVs in detail. Chapter Three presents logistical concerns that arise when using rapid acquisition. Chapter Four details the methodology behind the Logistics Implications Capabilities Assessment Model (LICAM). Chapter Five details other support issues found during the study. Following the Conclusions, Chapter Six, we provide four appendices, which provide supplementary information on the various U.S. UAV programs and can serve as a resource for UAV programs. The first three appendices are primers on Global Hawk, Predator, and small UAVs. Appendix D provides a comparison of many UAVs.

CHAPTER TWO

Current UAVs

UAV programs have been around since the end of World War II. But their military utility was generally considered small during the Cold War. By the early 1980s, this had started to change. The advent of enhanced satellite communications, miniaturized electronics, and sophisticated sensors (including relatively lightweight, highly capable synthetic-aperture radars [SARs]) fostered renewed interest in the potential capabilities of UAVs. The newly founded UAV Joint Program Office (JPO) produced the first UAV master plan in the mid-1980s. After various fits and starts, the JPO produced a plan in the early 1990s for a multitiered UAV concept.

The study team took a systems view of UAVs, dividing them into two broad classes by size: large and small. While vehicles could be classified according to their size, the defining measure is usually how the vehicle is controlled. Large UAVs typically have launch and recovery capabilities that can be separated from their control and data-exploitation capabilities; the latter are often operated using satellite links and reachback data exploitation. Small UAVs are typically launched, flown, controlled, and recovered and their data exploited by one individual, all within line of sight (LOS) of the vehicle.

This chapter provides an overview and comparison of the UAVs we reviewed for this report: Global Hawk, Predator, UCAV, Pointer, Raven, FPASS, and BATCAM. While it is not exhaustive, this chapter does provide insights into size, capability, capacity, sensor capability, and cost of some of the current and projected UAV systems. Appendixes A through C describe these systems in more detail.

Large UAVs

Large UAVs can typically be launched and recovered via LOS communications. The flight over the target area, as well as data and/or imagery the UAV records, can be sent to a separate location via satellite communications.

Global Hawk

Global Hawk is the offspring of an earlier Defense Advanced Research Projects Agency (DARPA) effort to develop a high-altitude, long-endurance (HAE) UAV; it is considered a Tier II+ HAE UAV.[1] The original HAE UAV program was part of a new acquisition experiment aimed at getting important military capabilities into the field quickly. Because Global Hawk is large and capable of long-endurance flights at high altitude, it is an excellent platform for collecting sensitive intelligence information from most parts of the world (see Figure 2.1).

There are currently two different versions of the Global Hawk vehicle—the RQ-4A and the RQ-4B. The following description is of the RQ-4B, the most current version of the vehicle at the time of this publication.

The Global Hawk RQ-4B vehicle has a 131-ft wingspan and a maximum weight of approximately 32,250 lbs. It was designed to have an endurance of at least 20 hours at a 1,200-nmi flyout distance, an operational altitude above 60,000 ft, and a maximum payload capacity of 3,000 lbs. The true airspeed of the RQ-4B is approximately 310 kts (Nunn, 2003).

This UAV's primary mission is ISR, and its current mission package consists of a set of optical sensors—electro-optical (EO) and

[1] In 1994, DARPA started an ACTD program that was to produce three HAE UAV platforms, labeling them Tier I, Tier II, and Tier III. Each had different design objectives. Tier 1 (the Gnat-750) focused on a loiter altitude of about 16,000 ft. The CONOP for the Tier II, Medium-Altitude Endurance (MAE) UAV (the Predator) included operating at altitudes no greater than 25,000 ft at airspeeds of 60 to 110 kts. Tier I and Tier II vehicles were not designed to be stealthy. The Tier III UAV (DarkStar) was designed to fly at altitudes over 40,000 ft and to be highly stealthy.

Figure 2.1
Global Hawk: A Large UAV

SOURCE: Nunn (2003), slide 2.

infrared (IR)—and a SAR. Future plans call for an enhanced payload that will provide such additional capabilities as a signals intelligence (SIGINT) sensor and an enhanced radar system that includes a ground moving target indicator (GMTI). These capabilities will be added through the Air Force's Multiplatform Radar Technology Insertion Program (MP-RTIP), during spiral development.

The Air Force currently plans to purchase 51 Global Hawks. The latest model, an RQ-4B, with no sensors, costs $32 million apiece, which includes recurring hardware, systems engineering and program management, tooling costs, as well as nonrecurring tooling costs. Purchasing a Global Hawk with a full sensor suite would cost $54 million. In addition, each ground station costs $16 million.[2]

The high altitude and the long operational radius allow great survivability and operational flexibility. In addition, the larger vehicle could accommodate additional avionics and/or devices.

[2] Cost data from ASC Global Hawk Financial Management (ASC/RGF), July 27, 2004.

Predator

The UAV JPO's plan from the early 1990s called for a multitiered UAV concept. One of these, Tier II, was known as the MAE UAV. In 1993, at the end of the planning phase, the Under Secretary of Defense for Acquisition, John Deutch, specifically criticized the MAE's planned design, stating a requirement for greater endurance capabilities. The "Deutch memo" stated the new requirements to be the capability to fly 500 nmi from an operating airfield to a target area, remain on station for at least 24 hours, have a payload capacity of 400 to 500 lbs, and fly at an altitude between 15,000 and 25,000 ft (Deutch, 1993). Because survivability at these altitudes was thought to be questionable (the UAV was not to be stealthy), the unit cost had to be low enough that the vehicle could be viewed as expendable. The unit cost cap was set at $5 million. A new UAV design resulted: the Predator.

Predator, considered a large UAV, was designed to be an inexpensive (and thus expendable) air vehicle that could loiter for up to 24 hours over a target area and relay back relatively high-resolution pictures of specific target areas on the ground. There are two versions of Predator today, Predator A and Predator B.

Predator A, originally designated RQ-1, was designed to provide persistent ISR coverage of a specified target area (see Figure 2.2). With a wingspan of 48.7 ft and weighing approximately 2,250 lbs, Predator A has a 24-hour endurance with a flyout distance of only 500 nmi. It has an approximate ceiling of 25,000 ft and can carry approximately 450 lbs internally and 200 lbs externally. Its maximum airspeed is 120 kts, but it loiters at approximately 70 kts (Office of the Secretary of Defense, 2002; U.S. Air Force, 2001; and Federation of American Scientists, 2002).

As an ISR platform, Predator A carries either an EO/IR sensor package or a SAR. The sensors are interchangeable and not as sophisticated as those on Global Hawk. Predator A (RQ-1) migrated into MQ-1 with the addition of a weapon-carrying capability. The vehicle can simultaneously carry EO/IR sensors and two Hellfire missiles.

Figure 2.2
Predator A: Originally Designed for ISR

SOURCE: U.S. Air Force (2005).

At the time of this study, the Air Force planned to acquire 15 Predator A systems and some attrition reserve.[3] Eight systems would be coded for combat, two for training, and one for test. Each vehicle costs approximately $4 million, significantly less than for Global Hawk.[4]

Predator's design is not static. An entirely new Predator has been designed and built (see Figure 2.3). Predator B (MQ-9) is substantially larger, with a wingspan of 64 ft and weighing approximately

[3] A system consists of four Predator vehicles, one ground control station (GCS), and one command station.

[4] Data from the Air Combat Command UAV Special Missions Office for Predator (ACC/DR-UAV SMO).

10,000 lbs. The published endurance is still 24 hours, but the flyout distance has increased to 1,000 nmi. At 45,000 ft, Predator B's ceiling is significantly higher than that of Predator A, which makes Predator B more survivable in some threat conditions. Predator B has an internal payload capacity of 750 lbs and an external capacity of approximately 3,000 lbs.[5] Its maximum airspeed is 220 kts, almost twice that of Predator A (Office of the Secretary of Defense, 2002).

Predator B's primary mission is time-sensitive targeting, which involves continuously monitoring suspected target areas and attacking targets promptly when they do emerge. Its laser designator and laser tracker allow the Predator B to attack high-value, newly emerging targets found by its ISR sensors rapidly. This Predator has an improved sensor suite, which, like Predator A's, is interchangeable.

Figure 2.3
Predator B: Adding a Time-Sensitive Targeting Capability

SOURCE: SPG Media (2005).

[5] Interview with ACC/DR-UAV SMO, staff, Langley AFB, Virginia, July 29, 2004.

The vehicle can carry both EO/IR sensors and a SAR and as many as four 500-lb precision-guided munitions.

As of the time of this writing, the Air Force had bought 89 Predator As and plans to acquire a total of more than 100. The Air Force currently owns nine combat-ready Predator Bs, plus two for training, and one for test and evaluation and plans to acquire a total of 60.[6] Each vehicle costs approximately $10 million, which is cheaper than Global Hawk but more expensive Predator A. See Table 2.1 for a comparison of Predator A and Predator B. Newer versions of both Predator systems are continuously being tested and that may further expand the air vehicle's capabilities.

Table 2.1
Comparison of Predator A and Predator B

	Predator A	Predator B
Projected fleet size	77	60
Approximate maximum takeoff weight (lbs)	2,250	10,000
Speed at altitude (kts)		
Loiter	70	200
Maximum	120	220
Wingspan (ft)	48.7	64.0
Maximum payload (lbs)		
Internal	450	750
External	200	3,000
Approximate ceiling (ft)	25,000	45,000
Endurance (hrs)	24	24
at flyout distance (nmi)	500	1,000
Primary mission	ISR	ISR
Sensor and weapons carried	EO/IR plus two Hellfires Or SAR	EO/IR plus SAR Four 500-lb PGMs
Sensor complexity	Interchangeable Medium	Interchangeable Medium
Cost ($M)	4	10

[6] The Air Force Chief of Staff recently said that the Air Force plans to buy as many Predators as the contractor can make and has pressed the contractor to double its production rate (Bigelow, 2005).

The Unmanned Combat Air Vehicle Program

The UCAV is envisioned as a large UAV used to suppress enemy air defenses and for strike missions in support of manned operations.[7] Currently, the Joint Unmanned Combat Air System (J-UCAS), a joint DARPA–Air Force–Navy initiative, is still under development. Figure 2.4 is the prototype X-45A, flown in November 2002.

The current prototype, X-45C, was being build for testing as of this writing. It has a wingspan of 49 ft and weighs approximately 35,000 lbs. The projected endurance is 2 hours of loiter with a flyout distance of 1,200 nmi. The vehicle is designed to fly at 40,000 ft while carrying a payload of 4,000 lbs. The payload could include

Figure 2.4
The X-45A: A UCAV Prototype

SOURCE: DARPA (2005).

[7] Any armed UAV can be called a UCAV. However, here we are referring to the UCAV Program.

eight small-diameter bombs, a 250-lb near-precision weapon, the full range of Joint Direct Attack Munitions. The vehicle will fly at an airspeed of approximately 600 kts (Boeing, 2004). The sensor packages have yet to be determined but are expected to be quite complex. The Air Force is designing the air vehicle to be stealthy. The projected Air Force fleet could consist of anywhere from 2 to 200 air vehicles. The final cost of a UCAV is not known but is expected to exceed $50 million.

At the time of this report, the Air Force and the Navy, working through DARPA, have asked for the range and endurance of the current J-UCAS to be increased. The redesigned air vehicle and the resultant support requirements are still under development.

Small UAVs

In 2001, AFSOC formed a team to help lead the way in the Air Force's acquisition of small UAVs. In December 2003, AFSOC was appointed lead command for small UAV issues and has divided them into four categories: micro, man-portable, multimission, and air-launched small UAVs.[8]

Micro-UAVs are used for individual situational awareness, have a range of 1 to 3 nmi, can only be used in daylight with fair weather conditions, and carry payloads weighing less than 0.5 lb. *Man-portable UAVs* have small-team applications, such as a look-over-the-hill capability; can be carried and launched by a single individual; have an endurance of 1 to 2 hours; and usually carry payloads weighing less than 50 lbs. *Multimission UAVs* offer high-value operational and intelligence support, such as psychological operations, resupply, ISR, and sensor deployment; have an endurance of 10 to 12 hours; and typically carry payloads weighing 50 to 250 lbs. *Air-launched UAVs* are projected to have an endurance of 9 hours, carry payloads weighing 20 lbs, and offer off-board capability for Air Force gunships.

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[8] USAF/XO Memorandum to AFSOC, December 31, 2003.

Typically, the imagery recorded by the air vehicle of most small UAVs is sent back to the operator, to be analyzed and exploited in real time.

Pointer

Pointer, a man-portable UAV, was designed to provide real-time data and precision delivery support to a wide variety of combat elements (see Figure 2.5). Its primary mission is surveillance using EO/IR and chemical-detection sensors. With a wingspan of 9 ft and weighing only 8.3 lbs, Pointer has an endurance of approximately 2 hours at an altitude of 500 ft, has a maximum airspeed of 88 kts, and carries payloads weighing a maximum of 1 lb (AeroVironment, undated). AFSOC received supplemental funding in FY 2003 to procure a total of 34 Pointer systems. A system of two Pointer air vehicles costs approximately $133,000.

Raven

Another man-portable UAV, Raven, has also been used to support U.S. Special Operations Command in the global war on terrorism (see Figure 2.6). Raven has provided real-time data on target acquisition and bomb damage assessment. About half the size of Pointer, Raven has a wingspan of 4.5 ft, weighs 3.8 lbs, and has a flight endurance similar to Pointer's, about 80 minutes with a flyout distance of approximately 6 mi (Parsch, 2004; AeroVironment, undated). Raven was designed to be a smaller, man-portable Pointer. At a maximum speed of 52 kts, Raven can carry the same payload as Pointer, approximately 1 lb. The standard mission payload is EO/IR sensors. AFSOC received supplemental funding in FY 2003 to procure 78 Raven UAVs. A system of two Raven air vehicles costs approximately $139,000, only slightly more than the Pointer.

Force Protection Airfield Surveillance System

FPASS, also often referred to as Desert Hawk (see Figure 2.7), is also considered man-portable. Used by Security Police, FPASS allows security forces to receive real-time surveillance of an airfield or limited

Figure 2.5
Pointer: An AFSOC Man-Portable UAV

SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

Figure 2.6
Raven: Another AFSOC Man-Portable Small UAV

SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

convoy operation. With a wingspan of 4.3 ft and weighing only 7 lbs, FPASS has a flight endurance of approximately 1 hour. Smaller than both Pointer and Raven, FPASS can fly up to an altitude of 500 ft at a speed of 30 to 42 kts. Carrying only EO/IR sensors, FPASS has no other payload capacity. The projected size of the FPASS fleet is

approximately 20 systems. A system of six FPASS air vehicles system currently costs approximately $300,000 (U.S. Air Force, Electronic Systems Command, 2003).

BATCAM

BATCAM is currently under development (see Figure 2.8). The Air Force has just begun testing prototypes of this vehicle. The system is designed to be man portable, with the collapsible-wing air vehicle fitting into tube with a 5-in diameter. The omnidirectional antenna is designed to fit into the upright posts of a backpack, and the ruggedized operator's computer console can be attached to a web belt.

This micro-UAV is smaller than Pointer, Raven, and FPASS. BATCAM has a wingspan of 1.9 ft, weighs only 1.5 lbs, has a flight endurance of only 30 minutes, a flight altitude of 500 ft, and a payload capacity of 0.5 lb. Built to provide "over the hill" reconnaissance, BATCAM carries EO/IR sensors. Since this program is still in the developmental phase, cost information is not yet available.

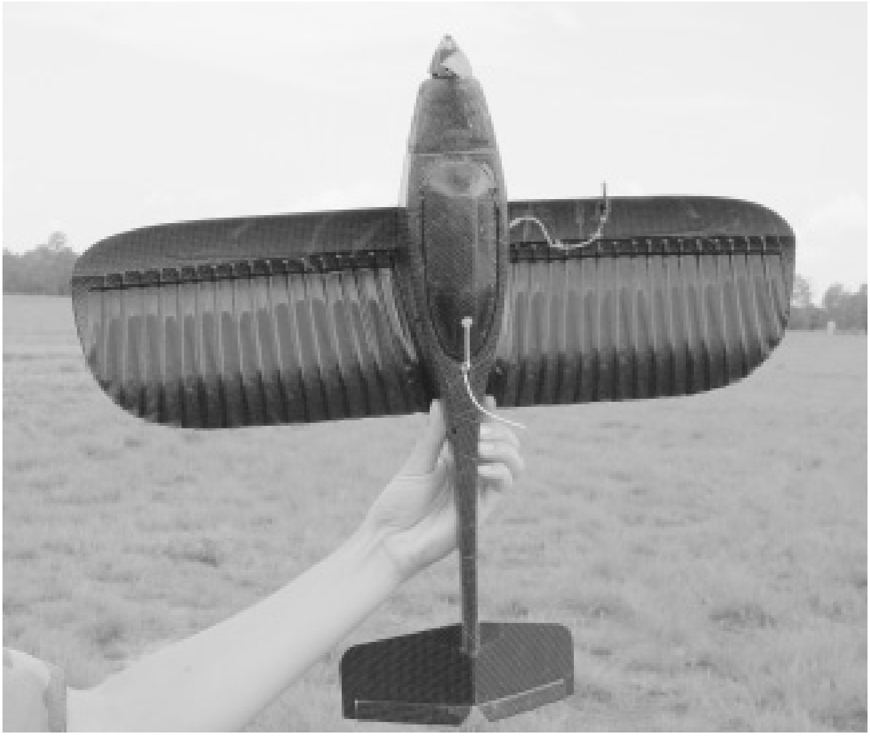
UAV Systems

While each of these systems, both large and small UAVs, has different operational and support requirements, they share many of the same issues. All the current UAVs have been acquired through either the ACTD or other rapid acquisition processes. Chapter Three will address some of the logistics issues associated with fast acquisitions and the UAV systems themselves.

Figure 2.7
FPASS: A Small UAV Used by Security Police

SOURCE: USAF Electronic Systems Command.

Figure 2.8
BATCAM: A Small UAV Currently Under Development



SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

CHAPTER THREE

Rapid Acquisition Logistical Support Issues

While not all Air Force UAVs have the same issues, many of the problems we found during this analysis were common to many of the systems in use today. In this chapter, we will discuss some of the issues inherent to rapid acquisition of UAV systems, including the ACTD process, system development and demonstration (SDD),[1] and spiral development. All these issues affect capability, which in turn affects support to the warfighter. We will also discuss how to better integrate rapid acquisition with support requirements.

The ACTD Process and SDD

Many of the UAVs the Air Force currently employs were originally developed as ACTDs. ACTDs, by design, demonstrate new technologies. The resulting prototype systems demonstrate a proof of concept. In most cases, the contractor develops the ACTD capability as inexpensively as possible and is not, and should not be, required to maintain or produce reliability and/or maintainability data. For example, in developing Predator, the contractor paid for most of the ACTD development. Since the contractor spent its own money, there was little incentive to add additional capabilities to the vehicle that were not already required to be demonstrated.

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[1] *SDD* is the current term for what was once known as *engineering and manufacturing development (EMD)*.

Ideally, an ACTD would demonstrate a capability and show military utility, and the resulting vehicle would then enter into a SDD cycle. The SDD would allow support concerns to be addressed prior to production of the vehicle. However, in the case of Predator, the desire to place the capability in the warfighters' hands far outweighed the necessity of an SDD.

Bypassing SDD has consequences. When these ACTD prototypes are used to begin production of the actual air vehicle, logistics has little influence on the production design. For example, in the case of Predator, the ACTD prototype is now the production vehicle. In some actual operational environments, the flight control servos have overheated, causing aborted missions. While such aborts are fairly rare, manufacturer and test personnel are trying to resolve the issue. Because we do not get to control where Predator will be used in future operations, this may continue to be an issue. This is just one example of the effects of using an ACTD prototype as the production vehicle.

In the long run, the lack of reliability and/or maintainability data can create issues for logisticians when allocating such resources as manpower, spares, and equipment. It is difficult to set appropriate levels of support when there are no data to guide allocation.

Logistics Requirements Determination Process

During a normal acquisition, a formal assessment of logistics requirements is used to determine appropriate levels of support. This requirement-determination process is data intensive. For example, the following data would be gathered:

- mean time between failures: the expected amount of time between failures of an aircraft subsystem
- repair cycle time: the total time after the failure that it takes for the part to be given to the repair facility, the repair is made and tested, and the part is returned to the requesting organization
- initial costs of the component
- repair costs.

Such data are usually not available until after an SDD or LSA has been completed. Since much of this information is not available to the Air Force during a rapid acquisition, traditional logistics requirements determination is not integrated into the process, which can affect future system support.

For example, such data were not acquired during the Predator acquisition. Without data on the parts and their inherent reliability, it is difficult for the Air Force to make informed decisions about spares support. Particularly troubling is the expense of some spare parts. At present, for some of these parts, it can take months for the original contractors to make repairs. As a result, the Air Force is running substantial operational (not enough spare parts) and financial risks.

Spiral Development

In a traditional acquisition, a system would be designed to meet certain requirements, then a prototype would be built and tested before production of the operational vehicle. But, under some circumstances, the need to field a functional system may be greater than the need for a system that meets all requirements. This has been the case for some current UAVs, whose prototype vehicles were quickly pressed into actual service, even as the overall production process was being accelerated; test, evaluation, and real-world operations were taking place concurrently. CONOPs changed constantly, driven by lessons learned from both operational use and technological advances. This, in turn, drove changes in the vehicle design, so that vehicle redesign became continuous. Yet the pace of events did not allow time for the prototype design to be updated with the design changes. All this compounded the usual production issues.

One way to gain control under such circumstances is to use *spiral development*.[2] Spiral development does, however, have its own set

[2] Spiral development is a way of reaching a goal through planned increments. Each step in the spiral represents a functional system providing a distinct subset of the final set of capabilities, each building on what has already been done. At any given point in the spiral devel-

of logistics issues. For instance, having different lots or blocks of vehicles, each of which may have a different design, makes contracting for long-range support difficult. Global Hawk is an example of a program using spiral development, procuring the vehicles by lots.[3] As a successful ACTD experiment, this UAV did not undergo a follow-on SDD. Spiral development gets the desired capability into the field quickly. However, following this process without planning for and funding significant retrofit could, in this case, create a fleet with many configurations. This could affect the establishment of mission-ready spares packages. In the case of Global Hawk, 14 different packages for the 14 different possible configurations could be necessary.[4] Neither option would be appealing to the logistics community. For Global Hawk, the spiral development approach to getting increasing performance capabilities into the field has also added an element of concern about long-term maintenance and support.

The authority to obligate money in the budget several years in advance can also make contracting for long-range production difficult. Historically, program objective memorandum (POM) estimates have been insufficient because of rising vehicle costs driven by changing and/or increasing requirements or cuts in future year programs. These insufficient POM estimates affect logistics when the desire for "iron on the ramp" outweighs the recognition of the need for support, such as technical orders, spare parts, and ground support or test equipment.

POM estimates have been insufficient because predicting future requirements in a build-to-buy environment is difficult. As men-

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opment, a vehicle could be built and existing vehicles would be retrofitted to meet current specifications

[3] In 1999, an intelligence program decision memorandum directed the use of spiral development so that Global Hawk's capabilities would evolve to fully meet the operational requirements document. Incremental improvements pertain to all aspects of Global Hawk, including its mission packages, the air vehicle itself, and the other elements of the system (for example, the ground stations).

[4] Since the completion of the research for this report, ACC has programmed $580 million in FY 2006 to improve the retrofit issue for Global Hawk. Specific plans are still in development.

tioned previously, the Air Force tried to slow the production of some vehicles, allowing leftover money to be used to address logistics issues. Congress intervened and directed that the vehicles be purchased as planned.[5] With no funding, logistic support issues were not addressed.

Increasing Capability by Improving Support Through Integrated Processes

Historically, logisticians have not always been able to effectively articulate the effects of rapid design and procurement realities on support, which ultimately affect operations. Rapid acquisition processes do not allow sufficient time for developing technical data and fully integrating training requirements. In spite of these circumstances, the Air Force was able to provide a capability that was much sought after and eagerly embraced by the combatant commanders and other senior leaders, as evidenced by its employment in Operations Enduring Freedom and Iraqi Freedom.

However, a balance must be struck between providing a new capability rapidly and assessing the long-term logistical support of the capability. Delaying the delivery of a new or improved capability to the front lines is undesirable; however, most would agree that the ability to provide the new capability must be weighed against its consequences for logistics in the long term. A system, regardless of operational capability, must be either expendable (one time use) or maintainable. This can be accomplished by keeping the cost of a capability low enough to make it expendable or designing the capability to be supportable and/or maintainable enough to make it reusable.

While cost is an important issue, it is also important to provide the ability to accomplish the mission or increase system availability. Understanding these factors and how they can influence operational trade-offs would be of value. Many times, simply understanding that

[5] Interview with ASC/RAB staff, Wright-Patterson AFB, Ohio, April 2004.

an operational decision will have logistics effects can be as enlightening as actually accomplishing analysis. Identifying the logistics areas that could be affected may, by itself, help alleviate the problems before they are encountered.

During any acquisition, all aspects of the program play in a trade space. The program is allocated a set amount of money per year. Improvements to technical data may outweigh the need to acquire improved training aids. Adding an additional capability could demand resources and thereby cause support equipment resource shortages, which would eventually affect availability in the field. To ensure a successful program, it is important to measure the effects of these adjustments and understand their long-term effects on support. However, logisticians often have trouble articulating the effects of some of the changes and translating them into operational metrics.

Traditional metrics, such as mission-capable rates, do not fully depict the capabilities of a UAV system. With one or more air vehicles and numerous GCSs assigned to support an operation, the mission-capable rates of air vehicles are not of direct interest to the operator. While the information is still useful, the operator is most concerned about the ability to provide the required coverage over a target or target area. The number of air vehicles that are not mission capable at any given time may or may not affect the Air Force's ability to cover a target at a specific time. On the other hand, a high air-abort rate could significantly affect the ability to provide specific coverage. The key metric is the ability to provide coverage, an operational metric. This metric could supplement traditional logistics requirement determinations and better integrate rapid acquisition with logistics support requirements processes.

Currently, traditional logistics requirement determination and rapid acquisition are not integrated. However, there may be other ways to address this integration. If an SDD or LSA is not completed, some of the necessary data could be estimated. Alternatively, implied values could be used to determine support requirements. If exact values are not available, a range of values could be explored to estimate support requirements. We will explore this concept further in Chapter Four.

CHAPTER FOUR

The Logistics Implications Capabilities Assessment Model

A key metric in assessing the effectiveness of support and acquisition policies is the capability of the UAV fleet to provide orbital coverage. Lack of thorough historical data, combined with other support and operational issues, highlighted the need for a comprehensive simulation model. We developed an Extend-based simulation model, LICAM, to evaluate the trade-offs between various operational and support parameters.[1] LICAM is a discrete-event stochastic simulation model that translates various high-level logistics parameters, such as fleet size, break rates, and repair rates, into operationally measured metrics, including the percentage of time a vehicle would provide coverage over a specific target area.

Any methodology, such as LICAM's, allows assessment of the complex trade-offs that are inherent in UAV operations. Such a methodology is well suited for our purposes here, for several reasons:

- *User-set data parameters.* Current and future UAV systems do not have historical data on performance metrics. LICAM allows the user to select and test a range of data parameters.
- *Accommodation of dynamic metrics.* The metrics of interest—orbit coverage and queue sizes at key maintenance points—are inherently dynamic, and a model like LICAM allows examination of key metrics at hourly intervals. For example, coverage requirements may change over time. Under such circumstances,

[1] Extend is a graphical user interface system and process modeling software package from Imagine That, Inc.

a force may miss only 5 percent of required coverage, but it may make a large difference in performance if the 5 percent was concentrated in critical times in the conflict.

- *Flexibility in setting time dimensions for the analysis.* Management decisions about UAV deployment and maintenance may be based on the temporal characteristics of individual situations. For example, LICAM will allow the user to measure the effect of egress and ingress time on the overall orbit coverage capability.
- *Variability in setting repair "modes" to analyze their effects.* UAVs may fail for many reasons, and each failure mode may require a different type of maintenance. LICAM allows several types of repair and maintenance options.
- *The capability to analyze spares and labor options.* Although LICAM does not currently model spares and labor explicitly, it does have the ability to assess the effects of both labor and spare parts on the operational capability of the UAV fleet.

Simulation Modeling

A simulation model, such as LICAM, attempts to predict the behavior of the system under investigation by replicating and analyzing the interaction among its components. It used to be necessary to compromise between a model that provided a realistic replica of the actual situation and one whose mathematical analysis was tractable. With the advent of faster computers and increased memory, we can develop a more realistic reflection of reality without compromising on mathematical rigor.

By expressing the interactions among the components of the system as mathematical relationships, we are able to gather information in very much the same way as if we were observing the real system (subject, of course, to the simplifications built into the model). Simulation thus allows greater flexibility in representing complex systems that are normally difficult to analyze by standard mathematical models. We must keep in mind, however, that a model by definition is not the real world, but a representation. No matter how hard we

try, we will miss many nuances of the real world. However, the model provides a way to begin to evaluate support options and operational trade-offs. In the end, we have to make some compromises to get reasonable results. We can reduce the effect of such compromises through additional analysis of the problem.

The user has the flexibility of defining various input parameters enabling exploration of a full range of operations. For current systems, users have the benefit of inputting actual data from recent operations. For systems still under development, the user can test a wide range of parameters and see the effects of varying inputs, thus realizing the sensitivity of some system parameters before system production.

In general, LICAM allows the user to define decision variables, such as the number of air vehicles assigned to the operating location. The user can set various operational goals, including length or duration of deployment and orbit time (that is, the time each individual air vehicle should remain over the target area). Constraints can also be applied. The user can input various parameters, including the distance the air vehicle will travel from operating location to target area, different types of failure rates, and delays for repair.

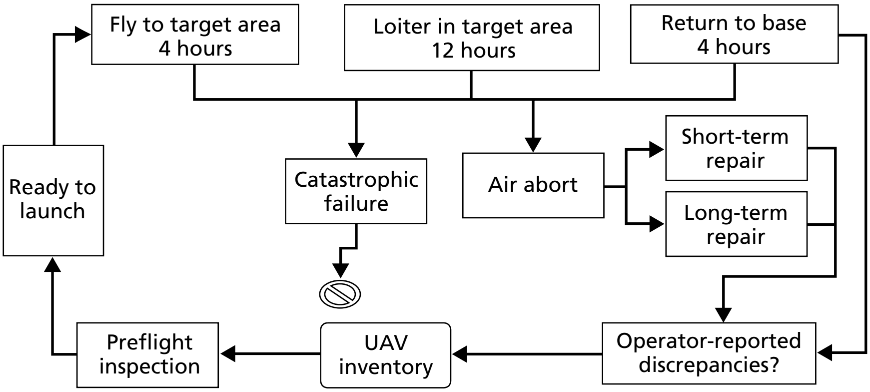
LICAM comprises several modules that perform different functions (for example, aging UAVs and repair). Each module may receive data as an internal parameter (from user input and default settings) or from the output of another module. Although the user can change each parameter, some of the internal parameters are specific to the model and rarely change. The following is a list of parameters:

- number of UAVs: X vehicles
- preflight inspection: X hours
- one-way transit time from target area to operating location: X hours (each way)
- orbit over the target area: X hours per vehicle
- failures and aborts; there are two types of failure at each stage (egress, ingress, and orbit):
  - catastrophic failure rate: X every 100,000 flying hours
  - air-abort rate: X per 1,000 flying hours

- air-abort maintenance times
  - minor repairs: an integer uniform distribution, with a minimum of X hours and a maximum of X hours
  - major repairs: an integer uniform distribution, with a minimum of X hours and maximum of X hours
- operator reported discrepancies: X-hour delay X percent of the time
- simulation duration: X hours.

Figure 4.1 illustrates the flow of the model. First, UAVs are queued for operation with the main goal of maximizing the coverage over the specific target area. Before operation, each UAV is inspected and, if fully mission capable, is launched. The model tracks the status of individual air vehicles as they launch from the operating base, fly into the target area (ingress), loiter over the target area performing the assigned mission (loiter), and return to the operating base (egress). At each point, each UAV is subject to failure from some external or internal cause. These failures are simulated by various probability distributions that are based on historical and engineering data.[2] If a

Figure 4.1
An Illustrative Example of LICAM



RAND *MG350-4.1*

[2] Historical data are used if available. If not available, the user sets the parameters.

UAV has a catastrophic failure, it is immediately pulled out of the system permanently. In case of an air abort, the UAV is forced to abandon its operation; if available, a new UAV is launched. The failed UAV is returned to base for repair. The repair time depends on the nature of the failure and may last from a few hours to a few days. The model also allows operator-reported discrepancies, which may delay the relaunch of the vehicle. The time to accomplish postflight inspections is accounted for in the preflight section of the model.[3] Repaired vehicles are returned to the pool of fully mission capable vehicles and are launched as needed.

The model keeps track of percentage of time a specific target is covered, the utilization of maintenance shops, and the utilization of individual UAVs.[4]

Illustrative Example

LICAM incorporates all stages of UAV operations. As an illustration of the model's use, we have applied LICAM to a notional operation (see Figure 4.1).

For this notional example, we assumed an operational goal of 95 percent or better coverage of a single target with a fleet of four air vehicles.[5] Other parameters include the following:

- preflight inspection requirement: 3 hours
- one-way transit time from target area to operating location: 4 hours (each way)
- orbit over the target area: 12 hours per vehicle
- catastrophic failure rate: 32 every 100,000 flying hours

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[3] Typically, a combined postflight-and-preflight inspection is accomplished after the air vehicle returns from flight.

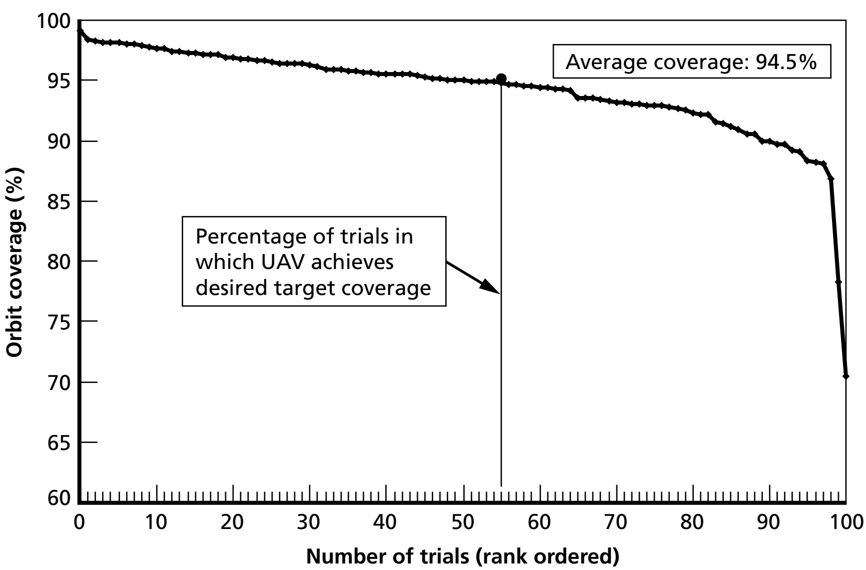
[4] LICAM tracks UAVs by their tail numbers.

[5] ACC's current UAV CONOP defines 95 percent as the desired operational goal (U.S. Air Force, Command and Control, Intelligence, Surveillance, and Reconnaissance Center, 2002b).

- air-abort rate: 18 per 1,000 flying hours (slightly less than 2 percent)
- air-abort maintenance times
  - minor repairs: 1–10 hours
  - major repairs: 24–72 hours
- operator-reported discrepancies: up to 10 hours of delay.

We ran this model for 90 simulated days (or 2,160 simulated hours). Figure 4.2 illustrates the results for 100 runs. The four UAVs were able to meet the desired operational goal (that is, the target area was covered about 95 percent of the time) in 55 percent of the trials. The range of coverage was as high as 98 percent and as low as 70 percent. This range of results is inherent in stochastic models and should be used as warning about putting too much weight on results from a single run. It is also interesting to note that there was a steady coverage of 90 percent or better for over 90 trials. In fact, the numbers on the right side of graph are low mainly because of one or two cata-

Figure 4.2
Baseline Results



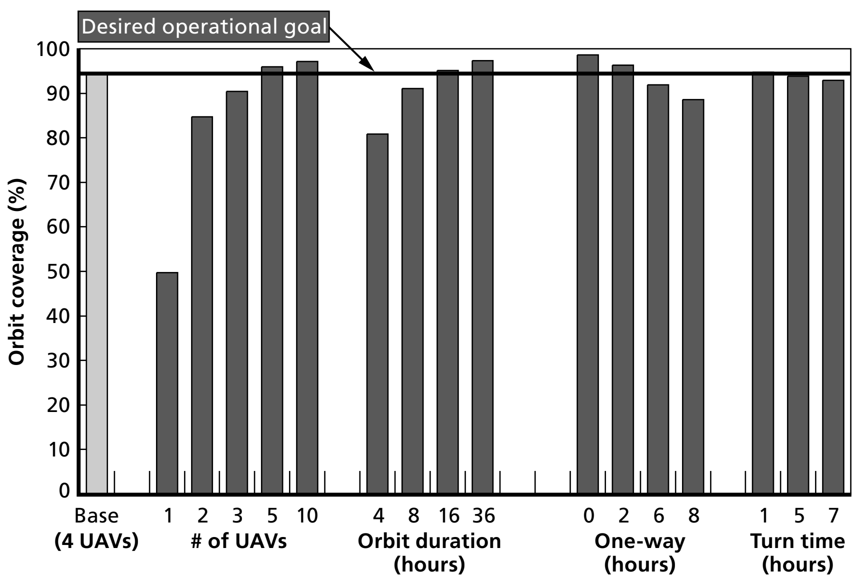
RAND *MG350-4.2*

strophic failures on those particular trials. Overall, this result shows that, for the given failure and repair rates, four UAVs can meet the stated operational goal more often than not.

The power of this model is in answering the "what if" questions. Figure 4.3 illustrates how some of the parameters affect the main objective, the orbit coverage. The first bar on left represents our notional baseline. The line across the top represents about 95-percent coverage of the target area.

The first group of bars, from left to right, represents the varying of only the number of air vehicles assigned to the operating location. All other input parameters remain the same. The difference in coverage between one and two vehicles is dramatic. However, increasing the number of air vehicles from 5 to 10 provides only a marginal improvement in coverage. This is an important point when allocating the air vehicles across different operating locations. For example, if

Figure 4.3
Sample LICAM Baseline Output Measured Against Operational Trade Spaces



NOTE: Baseline is 4 UAVs, 12-hour orbit, and 4-hour one-way transit time.
RAND *MG350-4.3*

there are only eight UAVs in the total fleet and given the above assumptions, a split of four UAVs per operating location is optimal because adding another vehicle to one location adds only marginal value to the receiving location but adversely affects the other.

The second group of bars depicts the effects of changing the orbit or loiter duration. In this example, the number of air vehicles is held constant (four) while the time the vehicle spends over the target area is varied. With the ingress and egress times set at four hours each way, the four air vehicles struggle to maintain 80-percent coverage while only orbiting for four hours. Conversely, extending the orbit to 36 hours produces only marginally better results than the 12-hour baseline. This is important when considering air vehicles with munitions. If weapons are expected to be discharged regularly and early during the orbit, the fleet size has to be increased dramatically to balance the shorter orbit duration.

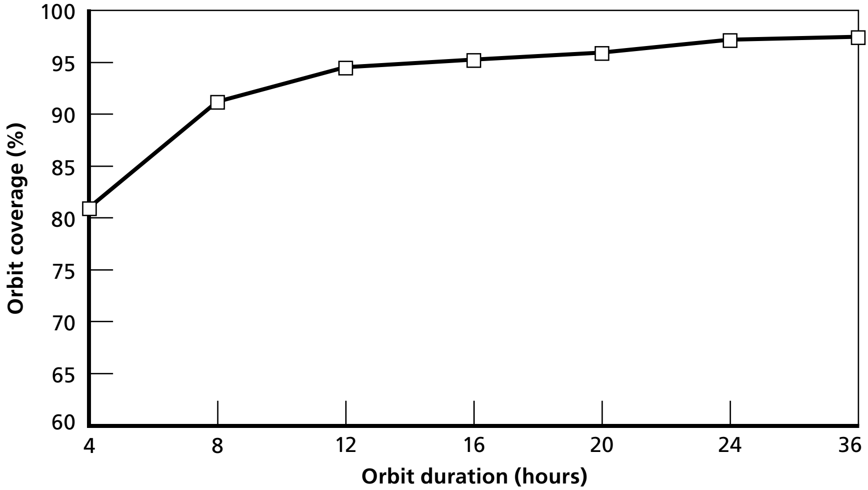
The third group of bars shows the difference in coverage when one-way travel time is varied. As the transit time increases, holding the other parameters steady, four air vehicles have difficulty maintaining the operational goal. Having the air vehicles at the target location or close to the target location (0 or 2 hours transit time) produces only marginally better coverage than the baseline four-hour one-way trip.

Turnaround times—the time it takes to service and return the vehicle to the serviceable inventory pool without repair—are depicted by the final group of bars. The turnaround times need to be longer than six hours before coverage is affected.

Using the same input parameters as above, Figures 4.4 and 4.5 illustrate a few more results of how varying these parameters affect meeting the operational goal. Figure 4.4 shows the effects of orbit duration on orbital coverage. The longer the orbit, the more likely four air vehicles will be able to provide 95-percent orbital coverage. With a shorter orbit, the ingress, egress, and turnaround times may be too long to support the required coverage.

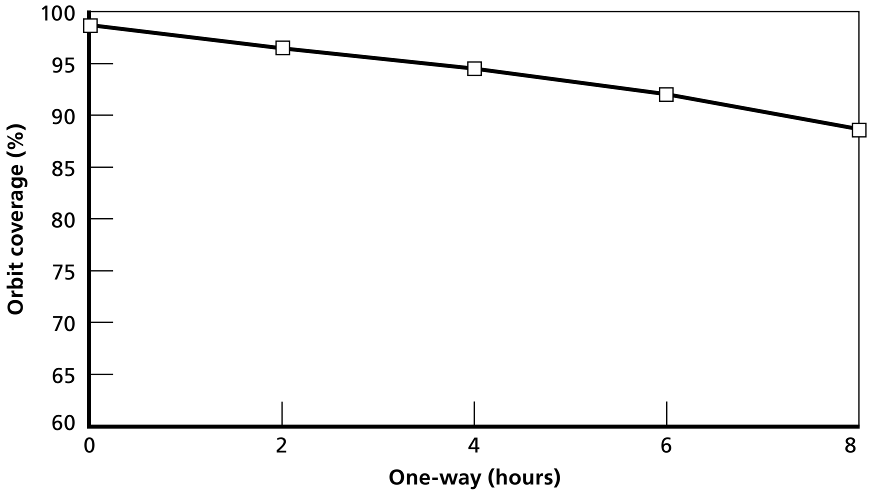
Figure 4.5 shows the effects of one-way transit time (ingress or egress) on orbital coverage. The longer it takes the air vehicle to fly to the target, the less likely the coverage requirement will be met.

Figure 4.4
Effect of Orbit Duration on Coverage



RAND *MG350-4.4*

Figure 4.5
Effect of Transit Time on Orbit Coverage



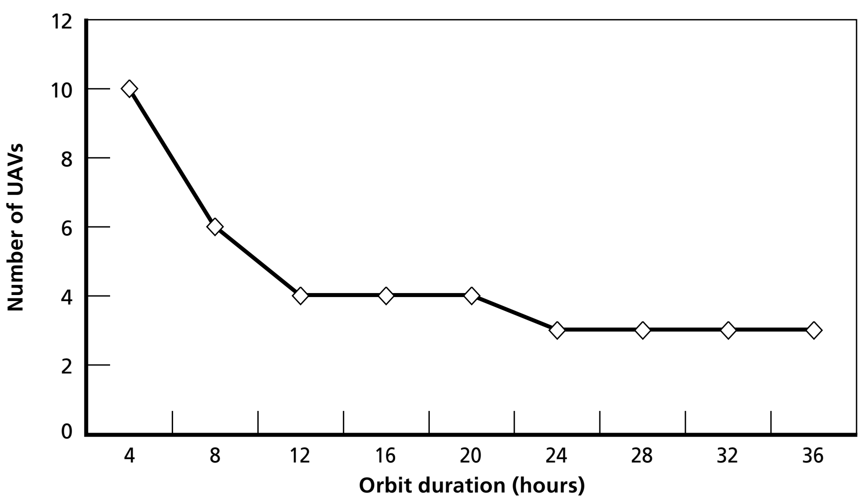
RAND *MG350-4.5*

The model could be used to evaluate trade-offs between various parameters. Figure 4.6 compares the effects of varying orbit duration and the number of UAVs to maintain a 95-percent operational coverage—the longer the orbit, the fewer air vehicles required.

The above results show the complex relationship between the various parameters and how we can examine the trade-offs between them. If the number of air vehicles were reduced by even one vehicle, the variance in coverage from altering turnaround times or orbits would be much greater.

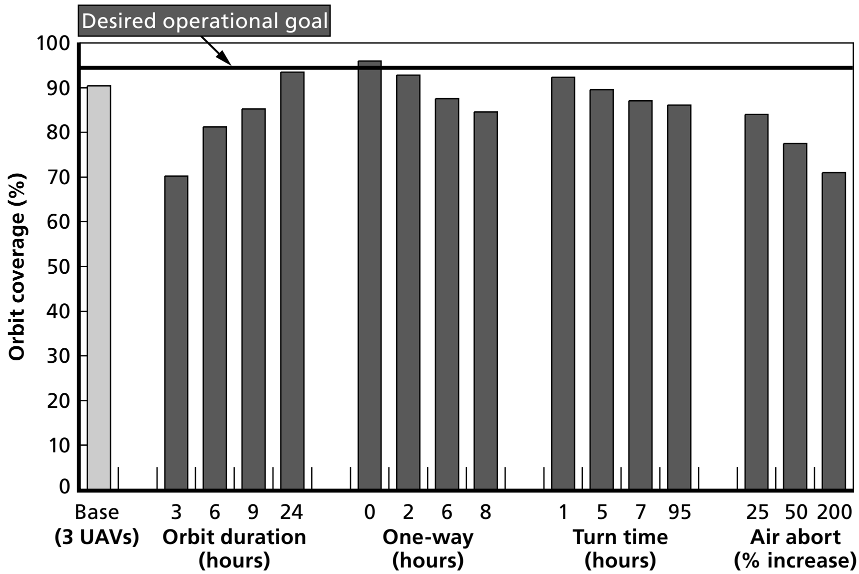
Figure 4.7 shows composite results, similar to those in Figure 4.3, but with only three UAVs in the fleet. As the figure shows, the 95-percent operational goal can no longer be achieved. However, if no additional air vehicles are available and if the 95-percent orbit coverage must be maintained, the operators must either expect a longer orbit duration (at least 24 hours) or shorter ingress and egress times (less than 2 hours). Any other constraint would drastically decrease the performance of the UAVs. It is interesting to note that even

Figure 4.6
Orbit Duration and UAV Trade-Offs



RAND *MG350-4.6*

Figure 4.7
Three UAV Results Measured Against Operational Trade Spaces



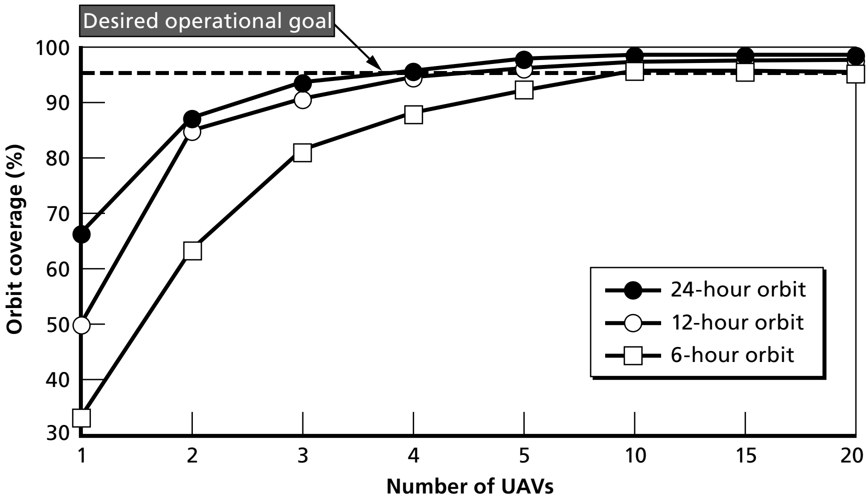
RAND *MG350-4.7*

reducing the turnaround time to 1 hour cannot increase the performance enough to achieve the 95-percent orbit coverage.

Figure 4.7 also illustrates the detrimental effects that increasing the air-abort rate has on orbit coverage. Increasing the current rate (18 per 1,000 flying hours) by 25 percent degrades the capability to about 82-percent orbit coverage. At 36 air aborts per 1,000 flying hours, the capability is only 70 percent.

Next, we looked at combining parameters in LICAM. Figure 4.8 is an example of the effects of orbit time and fleet size on the ability to provide coverage. The horizontal axis represents the number of air vehicles assigned to an operating location (inventory pool). The vertical axis is the percentage of time that coverage is provided. The desired operational goal, represented by the dashed line, is 95-percent coverage. The three lines represent varying amounts time an individual air vehicle will spend orbiting (loitering) over the target area.

Figure 4.8
Orbit Time and Fleet Size Affect Coverage



RAND *MG350-4.8*

With a 24-hour orbit, four air vehicles are able to exceed the goal. Additional air vehicles only produce marginal improvement. With a 12-hour orbit, it would take five air vehicles to exceed the goal. When the orbit is shortened to 6 hours, ten vehicles are required to provide the coverage.

Such comparisons could be helpful while the Predator B's CONOPs are being developed. For instance, what are the effects of the aircraft returning to base once its munitions have been expended? This type of model allows an exploration of these and many other trade-offs. The exact answers are not as important as understanding the possible effects of support on operational capability. This analytic methodology allows the user to express support issues in terms of operational metrics.

CHAPTER FIVE

Other Support Issues

Even with a model like LICAM, other logistical support issues need to be addressed in current UAV systems. This chapter covers several issues specific to Global Hawk, Predator, small UAVs, and contractor support.

Global Hawk Logistics Issues

Testing

Current systems have been tested, but the ability to address the test findings has been limited. For example, while a capable test group and the contractor have conducted tests of the Global Hawk vehicle and GCS, no money has ever been programmed to do anything with test findings. The test group, users, contractors, and the SPO compile a list of discrepancy reports for a Material Improvement Program Review board, which then reviews and ranks them. The Global Hawk program does address safety-of-flight discrepancies, but it is unclear whether it will address other discrepancies, such as support issues, at all, unless, perhaps, funds are programmed for FY 2007 or 2008. Additionally, evaluators felt the testing of Global Hawk was scripted and that the wording in the test contract was inadequate.[1] Future system programs should avoid testing without a plan to take action.

[1] Conversation with SMSgt Rodney Nearbin, 31st Test and Evaluation Squadron, Edwards AFB, California, March 2004.

Secure Communication Linkages

The Global Hawk wartime scenario requires a minimum of three air vehicles. It also requires one mission control element (MCE) and one launch and recovery element (LRE) (although the MCE requirement might be less if a reachback capability to the Beale AFB MCE is used). It also requires beyond-line-of-site (BLOS) communications, which in turn requires that the Air Force have satellite links available that can handle the necessary data rates. At present, many of these links are through commercial satellites. Availability and cost are important factors that should be planned into the system program. In the future, the Air Force expects to have access to the global grid and that the need to lease commercial satellite links will either vanish or be diminished. However, until then, communication linkages should be factored into the system requirements.

System Design

To save money during the ACTD phase, Northrop Grumman borrowed parts and designs from other programs. For example, Global Hawk uses the same hydraulic fittings and hydraulic fluid as the B-2. However, the fittings and fluid are used on only these two airframes. Since the rest of the Air Force does not use these fittings and fluid, these could become scarce resources, causing allocation issues.

Another example of a system design issue is the weight-saving technique of using heat from the air vehicle's electronics to heat the fuel. This keeps the electronics from overheating and warms the fuel for a more-even burn at altitude, except in hot climates, where there can be overheating issues. The avionics components of the Global Hawk sit on top of small radiator plates that carry jet fuel. However, when the vehicle is on the ground and as the radiator plates get hot, there is a fear of leakage and of fire. To reduce the probability of a fire, the equipment bays are purged with 99-percent pure nitrogen. Air Force–owned self-generating nitrogen carts do not produce nitrogen that is this pure, and buying 99-percent pure nitrogen is very expensive. During a deployment, there is also a question about the purity of the nitrogen a host nation might provide. Would a purity of

96.5 percent, the Air Force standard, be just as effective at preventing a fire?

Contractor engineering personnel, in addition to test personnel and representatives of the Air Force Research Laboratory, are continuing to work fuel-nozzle issues on Global Hawk. A flight-test evaluation of JP-8 plus 100 is ongoing at Edwards AFB, California, to determine whether coking can be reduced on fuel nozzles.[2] Currently, with JP-8 fuel and JP-8 plus 100, nozzles are being inspected every 150 hours. The JP-8 plus 100 is showing some promise. A reduction in coking has been found at the 150-hour inspection interval. However, when coking is found, the nozzles must be changed, which requires two technicians, three shifts, and $70,000 in parts per engine. In addition, another Global Hawk location that uses JP-8 has found much less coking. Therefore, the fuel nozzle investigation continues.

One particular line-replaceable unit (LRU) on the Global Hawk costs $4.3 million.[3] This LRU, the EO/IR receiver, has no built-in-test capability, and the contractor has only provided limited expected mean-time-between-failures data. Considering its cost and the lack of manufacturer data, this LRU is a prime candidate for further review, perhaps to pursue a course similar to the one the Navy took in procuring its Multispectral Targeting System (MTS) ball (see next subsection).

The Navy Multispectral Targeting System

The U.S. Navy depot at Crane, Indiana, is responsible for procuring and maintaining the original MTS used on Predator. The MTS is an expensive and sophisticated LRU. The ball consists of EO, IR, and laser sensors, as well as laser designators. The Navy has had previous experience with systems like the MTS, as well as experience with the MTS's manufacturer and repair times.

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[2] *Coking* is the buildup of residue on the end of the fuel nozzle from incomplete burning of fuel. This residue can effectively clog the ports in the end of the nozzle and cut off fuel flow. Global Hawk only has coking problems at high altitudes (60,000 ft).

[3] Interview with ASC/RGL staff, Wright-Patterson AFB, Ohio, July 28, 2004.

Given an initial procurement cost in excess of $1 million per unit (actual data from procured units), an anticipated high failure rate (previous experience with like LRUs), and a long repair cycle (previous experience with the manufacturer), the Navy decided to purchase all the manufacturing and design data from the contractor. With data in hand, the Navy was able to complete a SORAP and develop an intermediate and organic depot-level repair process to augment the manufacturer's repair process. We did not perform a cost-benefit analysis on these data, but the program office in Crane reports savings of many times the cost of the data.

Such analyses, with resulting savings, is not possible with every component on a sophisticated ACTD. Attention should be given to the components with the highest anticipated return. Expensive LRUs, components with high expected failure rates, or manufacturers with poor repair performance should be candidates for review.

Predator Logistics Issues

Manufacturer Facilities

All Predator production and component repair activities take place at one facility, including soldering circuit boards and winding alternators. The contractor is in the process of bringing a second facility on line. The contractor also has some capability at test facilities.

System Design

Both the A and B models of Predator are built by hand. Single layers of resin and cloth are applied one on top of the other, then the surfaces are hand sanded. This produces a highly effective and robust vehicle but limits the production rate. The contractor could gain some capacity by surging, but a significant increase in production rate would mean increasing both the physical area and the number of personnel.

Training

Building—and retaining—a well-trained cadre of Air Force personnel for maintaining future Predators has proven to be a challenge, even in peacetime. To start, no one Air Force specialty code meets most of Predator's maintenance needs. When the Air Force attempted to build a maintenance force for Predator, it drew from the aircraft maintainers that were in abundance elsewhere (from A-10 and F-15 squadrons). For the most part, their skills were not applicable to maintaining Predator. Lacking coherent technical orders from the contractor, it took the Air Force almost two years to suitably train its personnel. That meant that each individual was productive for only one year before completing his or her three-year tour working on Predator.

The training site at Indian Springs Air Force Station is at a remote location and thus is not favored by most of the personnel assigned there. In addition, maintaining UAVs is viewed as a dead-end duty. Current data show that a large number of those who have been stationed at Indian Springs have opted to go elsewhere (or, in some cases, to retire) after completing their three-year tours.

Part of the long-term solution may be to involve the Air Force reserve and guard. The reservists could be trained in maintaining Predator, making them available for forward deployment. The guard could be trained in doing many of the home-site jobs, where routine, long-term support would favor their status. The Air Force is investigating both options.

Pilot training is limited by lack of time. There have been relatively few Predator flights to date, and prior flight training and experience do not directly apply to Predator training. Many of the cues available to pilots in ordinary aircraft are not available (for example, there is no sense of the vehicle's motion) when flying the Predator. The ACTD program did not develop a flight simulator that the pilots could use in the absence of real training with Predator. And the situational displays on the pilot's monitor are currently better suited for engineering analysis (consistent with their use in the ACTD process) than for flying the UAV under real-world conditions.

One pilot-training issue that arises in peacetime training is the possibility of interference with commercial aviation traffic over the desert.[4] Predator's ability to see and avoid aircraft operating in the same airspace is very limited. The Air Force interacts with the Federal Aviation Administration to determine conflict-free paths on which the UAV may fly in training; learning how to successfully generate such routes is a training issue in itself. Unlike Global Hawk, the Predator does not fly above commercial and civil aircraft.

Average Production-Unit Costs

Arbitrary limits on average cost of a production unit—the total cost of the vehicle—can also negatively affect logistics support. For many systems, an upper ceiling or limit has been set. For example, Predator A has a cost limit of $5 million. Cost limits are designed to slow or stop cost increases driven by increasing requirements. However, an unintended consequence of this bound on spending is that, to remain within the specified cost limit, support considerations are often neglected. The cost limit hinders any attempt to retrofit because retrofits (even to fix problems to improve operational capability) would be counted against the vehicle and could push its apparent cost over the cap.

Secure Communications Linkages

For Predator to accomplish its mission, it must maintain a secure communication linkage with its GCS. Predator routinely uses commercial satellites as relays for sending its sensor data back to its GCS.

Small UAV Logistic Issues

Fuel and Battery Requirements

Most small UAVs use model aircraft fuel, aviation gas, or motor gas but no diesel. Some or all of these different types of fuel may be

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[4] This is also a potential issue when Predator is forward deployed.

unavailable, especially at a forward operating location. Currently, small-UAV operators are supplying their own fuel because their requirements are not part of the typical Air Force resupply and sustainment system.

Batteries are also an issue. Some small UAV systems use single-use lithium batteries, and others use rechargeable batteries. Logistical support for small UAVs needs to include a method for disposing of and/or recharging used batteries. Establishing a single requirement for one type of battery (and fuel) would alleviate sustainment issues.

Multiservice System Acquisitions

Pointer and Raven, two man-portable UAVs, are being acquired by U.S. Special Operations, the Army, and the Air Force. Each service may develop a different set of requirements, but they should consider common solutions for sustainability and cost purposes. As the Army purchases more UAVs, the services should continue to work together as they have with Pointer and Raven purchases and sustainment. With commercial-off-the-shelf systems, requirements need to be flexible to aid in the transition to functioning systems.

Maintenance at Forward Operating Locations

Most small UAVs are made of composite materials. During their employment, the air vehicles can be smashed, cracked, chipped, or dented. Air Force personnel who operate the small UAVs are usually not trained to repair composites. The issue becomes a question of what level of repair should the Air Force engage in, especially at a forward operating location.

Contractor Support Issues

For Predator, at present, most of the support personnel at the forward operating location (a remote site) are contractors. At one point, the Air Force was determined use its own personnel to populate the entire support contingent. However, once the difficulties of this became apparent, the Air Force adopted a more balanced approach

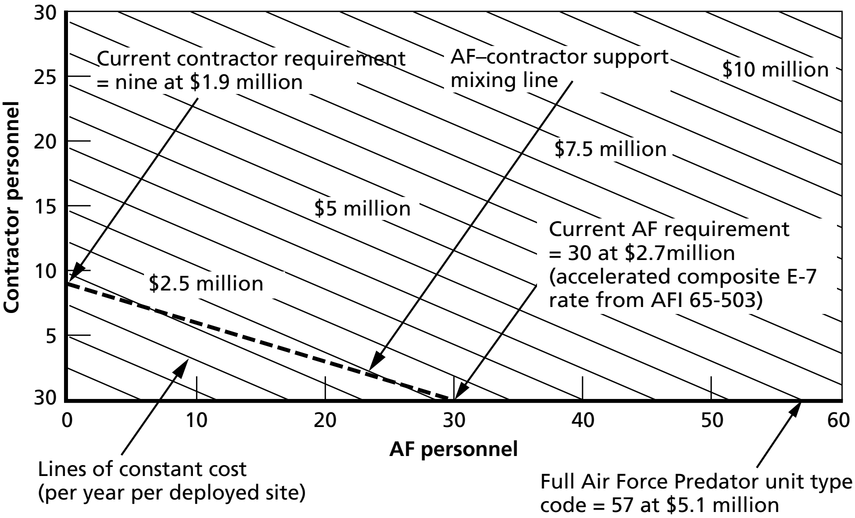
that involved both contractor and Air Force personnel. The technical data and other documentation needed to support a pure Air Force maintenance approach had only partly been funded, and none of the standard logistics planning documents had been prepared.

Comparing contractor against organic support again brings up the issue with the lack of integration between traditional logistics requirement-determination processes with the new, rapid acquisition process. The traditional level-of-repair assignment process is data intensive. The data required for the analysis are not available in a rapid acquisition; thus, it is difficult to determine the optimum split between contractor and organic support. Support and test equipment design and manufacture, while often lagging in a traditional acquisition, are often nonexistent in a rapid acquisition. A full cost-benefit analysis would require a baseline either for the contractor's capability or the Air Force's organic capability. In the current UAV programs, both have been in a state of flux.

The team looked at recent Predator deployment data for both contractors and active-duty personnel and was able to develop cost curves to compare the options. Figure 5.1 compares the number of Air Force personnel (x-axis) to the number of contractor personnel (y-axis) as a function of the cost.
In current Air Force Predator operations, contractor personnel are deployed to a forward site to provide launch and recovery capabilities and to make some repairs. The air vehicles are being directed and flown over the target area from a separate location. The contractor support replaced active-duty personnel who had been deployed to the site. The Air Force unit type code for Predator deployment support is fairly new and is being constantly updated. The full unit type code calls for 57 airmen to be sent to support a typical UAV system deployment, some of whom are pilots, intelligence specialists, and weather observers, and some serve other functions at a separate location.

It takes approximately 30 active-duty personnel to perform the mission. This number represents maintenance and launch and recovery capabilities. It does not include the security or other support

Figure 5.1
Predator Contractor Versus Organic Support Costs



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forces that may be required. The contractor requires nine personnel to provide roughly equivalent support. There are several reasons for this discrepancy. Active-duty airmen and contractor personnel do not work the same hours. A contractor will work 18 hours if required. Air Force Instructions (AFIs) restrict active-duty personnel to 12-hour shifts.[5] In addition, one contractor may be qualified on many systems. The Air Force takes a more-specialized approach, with one person being qualified on only a few systems.

Even when all this is considered, it costs roughly the same for contractors or active-duty personnel to provide the support. Referring to AFI 65-503, we used the rate the government charges for an E-7 to a non-DoD consumer to price the cost of the average deployed active-duty member. Multiplied by 30, the cost is approximately $2.7 million per year. ASC/RAB uses a planning factor of $100 per hour

[5] Maintenance group commanders may waive the 12-hour limitation and extend work up to 16 hours, as long as personnel are provided 8 hours of uninterrupted rest (Office of Freedom of Information and Security Review, Arlington, Va., August 3, 2005).

for contractors, resulting in a cost of approximately $1.9 million for nine deployed contractors.

The cost difference, which may seem negligible, is not the only reason contractor support may be valuable. For example, the contractor has continually shown the ability to react quickly to changing CONOPs and missions. The contractor work force comprises mostly skilled mechanics with exceptional knowledge of the air vehicle. By contrast, the Air Force does not hire highly skilled mechanics; it "raises" them.

Current UAV fleets represent a small fraction of the total force. Active-duty members rotate through a Predator or Global Hawk assignment as they would any other. They are given initial training, field training, and on-the-job training. Once they have proven proficiency, they are able to work independently. However, they need explicit technical data and procedures to do their job well. Highly skilled contractors, on the other hand, may be able to work from engineering and manufacturing drawings without explicit technical data.

During a deployment, numerous other support personnel are required to deploy to support an active-duty member, such as security forces; medical; cooks and other service providers; morale, welfare, and recreation personnel; and personnel specialists. Some of these support personnel may not be required for a contractor-supported deployment.

However, the Air Force faces other issues when reviewing support from the contractor. Using professional contractor staff to perform the support functions is apparently cheaper and (arguably) operationally better. However, contractors provide support at their discretion. Although it has not yet been an issue, the contractors could decide that the job was too dangerous for them to forward-deploy to the remote site. And, in any case, the reliability of such deployments is subject to the contractors' ability to get and keep volunteers who are willing to deploy. Continuous hardship deployments to remote locations may have the same effect on contractors as it has had on the services. Other issues could include labor disputes. Although there is no evidence that the Predator contractor will not be

available, the Air Force intends to train and retain competent Air Force personnel to do the job.

Recent history has shown contractors to be reliable and willing to accept the risks of being in hostile areas. The bigger risk appears to be the Air Force's ability to remain a contractor's number-one priority. As UAVs become more widely accepted and as the contractor customer base expands, the Air Force could find itself hard pressed to convince the contractor to concentrate on Air Force needs. Couple this with a continuing desire to pursue the latest and greatest technology, and the Air Force could face serious contractor-support issues as current systems become legacy systems.

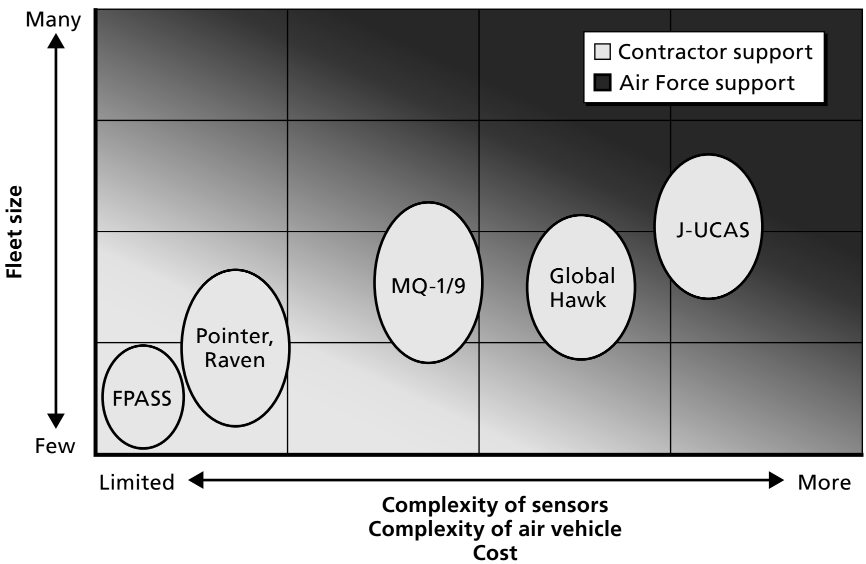
The ability to build and sustain an organic repair capability at the organizational, intermediate, or depot level should be weighed against the projected return on the investment. For Predator, the ACTD acquisition process used and the CONOPs in place drove the decision for a two-level maintenance system. Given their inherent maintenance skills and knowledge, the contractor's field support personnel provided some intermediate-level maintenance for the vehicle. In large part, this was not true for the mission payloads.

The Air Force has adopted a policy of looking at future decisions on levels of maintenance and making them individually, based on the cost-effectiveness. No simple methodology will work in all cases, which raises such questions as whether the Air Force can sustain a UAV maintenance career field; whether it needs these manpower slots for other, more-critical positions; whether the testers are small enough; whether the capacity exists to build an intermediate-level repair capability; and whether certain manufacturer processes are better suited for organic repair.

We have created a matrix that may help the Air Force think about how to address these and other support issues (see Figure 5.2).

The horizontal axis in Figure 5.2 depicts three areas that our review has shown to be closely related. The complexity of the sensor suite, the complexity of the air vehicle, and the overall cost of the system all increase at roughly the same rate. The more complex the air vehicle is, the more complex the sensors are. Conversely, the simpler

Figure 5.2
The Effects of System Complexity on Support Requirements



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the sensors are, the less costly the system is. The vertical axis represents fleet size from small to large. The light areas of the chart indicate preferred contractor-provided support, and the darker areas represent preferred organic Air Force support.

FPASS, Pointer, and Raven are all fairly inexpensive and simple UAVs with fairly small overall fleets. While the operators will remain organic, the repair and support are best provided by the contractor. These relatively inexpensive vehicles, coupled with a rapidly expanding technology and production capabilities, could lead many to believe they will be replaced with new, more-advanced UAVs in the near future, thus negating any potential return on investment in organic support. However, if the services were to agree on a family of small UAV capability (an AFSOC proposal), the Air Force might want to reconsider organic support.

As previously shown, the relative costs of contractor-provided and organic Air Force support for organizational-level Predator sup-

port will not drive the decision. To date, the system has been used effectively under both contractor and organic support concepts. Predator systems have benefited from contractor support; for example, the Predator contractor could provide new capabilities quickly. Conversely, that contractor has been slow to provide technical data. Also, the Air Force has benefited from the Navy's approach for the MTS (one of the few systems on the air vehicle not owned by the contractor). The Air Force's current support concept seems to have placed the contractor in a difficult position, because the contractor provides support only in remote, deployed locations and at the test facilities. As the Air Force has learned, this can create long-term health and happiness issues for contractor personnel. If the Air Force wants to keep the contractor personnel at deployed locations, it may also want to consider allowing the contractor to conduct some training operations, thus allowing it to rotate personnel. The Air Force may have benefited from buying design supportability and maintainability data from the contractor early in the program. Attempting to buy any additional data at this point, however, would be futile. As one member of the company pointed out: "Tell me the value of the company, and I'll tell you the value of the data." Without design or manufacturing data, the Air Force can do little to move the intermediate- or depot-level repair to an organic capability.

Global Hawk is projected to have a fairly large fleet and has complex and costly systems. While some of the sensor suites may be upgraded as new technology advances, the overall vehicle will probably remain in the active inventory for some time. This, coupled with the fact that Global Hawk is essentially a small manned vehicle minus the pilot, makes the system a good candidate for all levels of organic support. The plan for contractors to support this vehicle while stationed at permanent overseas locations raises the question of why any blue suit organizational-level support would be necessary. If the decision is made to have organic organizational-level support, the Air Force would benefit from contractor assistance with the complex sensors (as was the case with U-2). There are many possible candidates

for organic depot repair, including the $4.3 million LRU on Global Hawk.[6]

The current J-UCAS, with improvements the Air Force and Navy have requested, could become extremely complex and expensive. If the Air Force is going to pursue buying many of these systems, it should begin to consider moving support from the contractor to an organic capability for organizational-, intermediate-, and depot-level maintenance as early as possible.

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[6] Interview with ASC/RGL staff, Wright-Patterson AFB, July 28, 2004.

CHAPTER SIX

Summary and Conclusions

Current UAV systems and all associated equipment, including LREs, GCSs and their antennas, and the actual vehicles, represent a fairly small portion of the Air Force budget. The individual systems are relatively reliable and inexpensive (except for Global Hawk and UCAV), and the fleets are small. Regardless of the support concept employed or investments in technology, there is no readily apparent way to achieve major savings. However, we offer several recommendations to improve the acquisition and support of these and other new capabilities that could save costs for future systems. This report reviews systems that the Air Force currently owns or is acquiring and is not critical of what the Air Force has purchased to date. We review the acquisition process only in terms of identifying ways to aid future acquisitions.

Use analytic tools and methodologies to examine acquisition and logistics trade-offs. The logistics community has limited experience dealing with rapid acquisition. A model, such as RAND's LICAM, could be used to help bridge the gap between traditional methods of determining logistics requirements and rapid acquisition. A model could be used to help logisticians examine the trade-offs involved with many of the unknowns they might face early in a rapid acquisition. The model can simulate changes in fielding, operations, and support and can translate them into an operational metric, the ability to cover the target area.

Gather key supportability data, even during rapid development. Acquiring key maintainability and reliability data for a few

select components could greatly enhance the supportability of the fielded systems, ultimately reducing Air Force costs.

Structure sharing of acquisition and operational experiences and lessons learned. Current acquisition and support capabilities are spread throughout the Air Force and DoD. While the same could be said about fighter aircraft acquisition—with one program office in Ogden, Utah, and another at Warner Robins AFB—the difference with UAVs is that they represent an emerging technology, and the lessons learned at one location could apply for all locations. ACC recently held the first conference on remotely piloted aircraft, and AFSOC sponsored a small UAV conference in 2004. Both these efforts are steps in the right direction for sharing the knowledge gained from these new systems.

The division of responsibility can also cause disconnects between actions taken for the sake of rapid acquisition and those taken for long-term sustainment. The SPO best suited to do rapid acquisition may not have experience with continuous sustainment issues. One major command may be perfectly comfortable with rapid acquisition and manufacturer-provided contractor support. But another major command may want the ability to compete the contract to divide the support requirements among several contractors. Regardless of the support concept for each individual system, valuable lessons can be gained that may be lost without a structured sharing process.

Supply funding for remediation of problems identified during rapid acquisition and testing. There are several logistics issues that the Air Force could address to enhance future UAV development. For example, the Global Hawk has undergone extensive test and evaluation at Edwards AFB, California. However, there was no funding for evaluating or solving problems (other than those related to safety of flight), such as logistical support issues. A Material Improvement Program Review Board has been established and is in place to rank issues found during testing. Future systems could build early funding into the program budget to allow discrepancies found during test and evaluation findings to be addressed.

Limit the number of configurations within a fleet. Global Hawk air vehicles are being constructed in lots using spiral develop-

ment. Each block could have a different technological configuration. There is currently no plan for the Air Force to retrofit the air vehicles.[1] If spiral development is used in future systems, perhaps the Air Force should have a plan in place to standardize the airframe before production begins, to alleviate logistical issues.

Apply these recommendations to future systems (such as the UCAV). Looking at future systems, the Air Force and the Navy, working through DARPA, have asked for increases in the range and endurance planned for J-UCAS. The revised air vehicle and the resultant support requirements are still under development. However, if this vehicle becomes highly complex and expensive, if the Air Force buy is sizable, and if the program follows the Predator and Global Hawk example, support issues could become troublesome.

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[1] Since the completion of the research for this report, ACC has programmed $580 million in FY 2006 to improve the retrofit issue. Specific plans are still in development.

APPENDIX A

Global Hawk

This appendix describes some of the general characteristics of the Global Hawk program. It will cover the program's history and will describe the air vehicle and the ground modules. It will discuss Global Hawk's CONOP and acquisition plan, including some of the vehicle's capabilities. This appendix is not intended to be comprehensive but has been structured to provide some details not provided in the main report.

System History

Global Hawk is a large UAV designed to be capable of high-altitude long-endurance flights. The capability makes it an excellent platform for collecting sensitive intelligence information from many parts of the world. For many missions, it can be viewed as a substitute for the retired SR-71 and an alternative to the still-in-use U-2, both of which are manned reconnaissance vehicles. This UAV can position itself over an area of interest for 24 hours or longer, achieving a degree of persistence not obtainable from either manned aircraft or spacecraft.

The lack of "persistence" has long been stated as a major deficiency in U.S. intelligence-collection capabilities. Orbiting satellites revisit specified targets only a few times a day and on a predictable

schedule.[1] An enemy discovering that schedule can "hide" from satellite observation. Manned aircraft (for example, the U-2), while not as predictable as satellites, can stay over a specified target area for only a short time. Their small inventories make revisiting these areas infrequent in most circumstances. Global Hawk, in contrast, can orbit over a specified area for 24 hours or longer, continuously streaming data on the target area back to the United States for near-real-time processing and dissemination. The ability to gain an enhanced degree of "persistence" was probably the strongest argument for acquiring Global Hawk.

Global Hawk is the offspring of a DARPA HAE UAV effort. The goal of that effort was to produce three high-altitude, long-endurance platforms—Tiers I, II, and III—each having different design objectives. The Tier I vehicle, Gnat-750, focused on loiter altitudes of about 16,000 ft (UAV Forum, 2005). The CONOP for the Tier II MAE UAVs (such as Predator) includes flight at altitudes no higher than 25,000 ft at airspeeds of 60 to 110 kts (ACC, 1996). Tier I and Tier II vehicles were not designed to be stealthy. The Tier III vehicle, DarkStar, was designed to fly at altitudes over 40,000 ft and to be highly stealthy. Global Hawk is considered a Tier II+ HAE UAV.

The original HAE UAV program was initiated in 1994 as part of a new acquisition experiment by DARPA, aimed at getting important military capabilities to the field quickly. Called an ACTD, this type of capability demonstration was originally designed to shortcut normal weapon-system acquisition development cycles and to expedite fielding of valuable military capabilities. A normal ACTD would have a contractor build a small number of prototype vehicles that would be capable of demonstrating whether or not a useful military capability could be realized.

The DARPA ACTD resulting in Global Hawk was originally broken into three phases. The first phase was a six-month initial

[1] A geosynchronous orbit allows a satellite to hover in one location; however, a satellite may not be available to hover over the target area. Other limitations to using geosynchronous satellites include the distance from the satellite to the target and availability of orbital slots.

design effort involving five contractors. In phase two, the original plan was to downselect to two contractor teams that would have 27 months to complete the design and produce a prototype system, including initial flight testing. However, because of a budget cut at the start of phase two, only a single contractor team—Teledyne Ryan Aeronautical, the lead contractor—was put under contract to build the prototype UAV. Because of cost increases associated with the vehicle's development, phase two was more expensive and took longer than planned, which shortened phase three. Phase three was intended to be an extensive demonstration and validation activity. However, early in this phase, sufficient data on the vehicle's performance were available to make a solid judgment about its military utility. This vehicle, Global Hawk, became an Air Force program and went straight to an expedited acquisition phase.

The Air Force took over management of the program in 1998, early in the ACTD demonstration phase. The assessment of military utility was completed in 2000, confirming Global Hawk's military utility and leading to a decision to deploy the capability rapidly. One of the early vehicles was flown extensively in Operation Iraqi Freedom, gaining endorsements from the senior military commanders and supporting the decision to proceed with rapid acquisition. Low-rate production was approved for the vehicle, along with spiral development activities that would enhance functionality and performance.

The Global Hawk Systems

The Air Vehicle

The Global Hawk program is developing two vehicles (RQ-4A and RQ-4B), one considerably larger than the other. RQ-4A is essentially the vehicle that came out of the ACTD. Its overall mission payload capabilities were judged insufficient to meet the stated operational requirements, so a larger, more-capable version of Global Hawk was initiated. Table A.1 provides some data on the two Global Hawk air vehicle configurations currently being manufactured.

Table A.1
Global Hawk Characteristics

	RQ-4A	RW-4B
Specifications		
Wing span (ft)	116	131
Length (ft)	44	48
Height (ft)	14	15
Performance		
Range (nmi)	9,500	9,500
Total endurance (hrs)	28	28
Endurance at 1,200 nmi (hrs)	20	20
Altitude (ft)	60,000	60,000
True airspeed (kts)	340	310
Maximum weight (lbs)	26,750	32,250
Payload weight (lbs)	2,000	3,000
Payloads	EO/IR SAR	EO/IR+ SAR+ MP-RTIP SIGINT

SOURCE: Nunn (2003), slide 7.
NOTE: EO/IR+ and SAR+ indicate advanced sensors.

Global Hawk (RQ-4A) was originally designed to have an in-flight endurance of at least 28 hours,[2] an unrefueled flying range of at least 9,500 nmi, and a maximum operational altitude above 60,000 ft. With a true airspeed of approximately 340 kts, the RQ-4A air vehicle can maintain a 24-hour orbit over an area of interest, assuming a forward support base was within approximately 500 nmi of that area. The maximum payload for RQ-4A is approximately 2,000 lbs, with a mission package consisting of visual (EO/IR) and radar (SAR) imaging sensors. The RQ-4A first flew in February 1998 and was first used in an operational setting during Operation Enduring Freedom, from November 2001 through October 2002.

RQ-4B is intended to supplant RQ-4A as the prime Global Hawk air vehicle (the Air Force plans to have only seven RQ-4A Global Hawk vehicles built).[3] It is substantially larger, can carry a

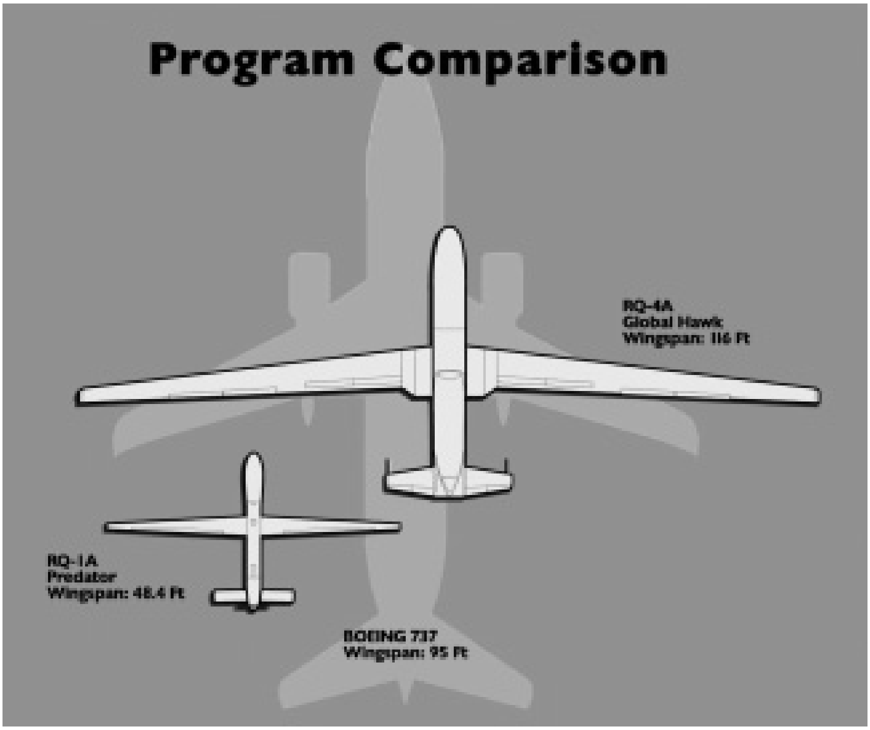
[2] This value was taken from Nunn (2003). Other informed references offer estimates of Global Hawk's maximum endurance at 32 hours and longer.

[3] The actual and planned buy of these two vehicles will be shown later in this appendix.

payload of approximately 3,000 lbs and has an improved operational range (not shown in Table A.1). The larger payload enables additional capabilities (for example, a SIGINT sensor package).[4] The higher altitude and longer operational radius enhance the air vehicle's survivability and operational flexibility. The larger vehicle also opens up opportunities to add some self-defense avionics or devices to the UAV.

Figure A.1 compares the size of Global Hawk (RQ-4A) to that of another UAV (Predator) and to a common midsized commercial

Figure A.1
Comparison of Global Hawk RQ-4A with Predator and a B-737



[4] Improvements to Global Hawk's mission payloads will be made in discrete steps. We will provide additional details on these and their contents later in this appendix.

airliner, the Boeing B-737. Global Hawk's 116-ft wingspan is more than twice Predator's and is longer than that of the commercial jetliner. RQ-4B's wingspan is even longer, measuring 131 ft.

Figure A.2 shows a Global Hawk in flight. The bulbous front end of the air vehicle houses most of the electronics and a large antenna for high-baud-rate communications via satellite to the ground stations. The vehicle's sensors are located toward the front and along the bottom of the aircraft.

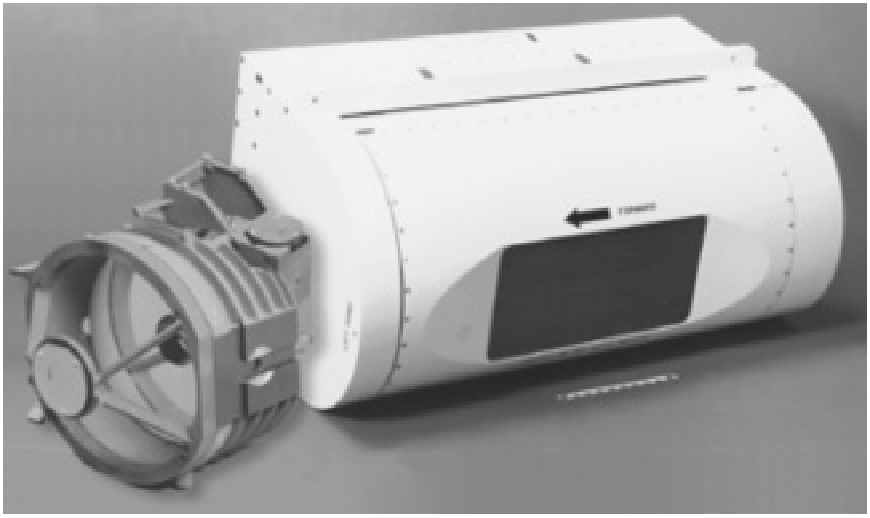
The RQ-4A has a sophisticated set of imaging sensors. The air vehicle has optical sensors—which passively detect visible and IR radiation from the ground—and SAR—which illuminates the ground and processes the resulting radio frequency returns.

A receiver unit (see Figure A.3) houses both the EO and the IR sensors. The EO sensor provides the highest resolution but works

Figure A.2
Global Hawk in Flight

SOURCE: Nunn (2003), slide 6.

Figure A.3
Global Hawk EO/IR Sensor Receiver Unit



SOURCE: Nunn (2003), slide 11.

only in daylight, cloud-free, LOS conditions.[5] The IR provides only slightly less resolution and also requires a cloud-free, LOS viewing path but can obtain useful images at night. The EO/IR sensor package weights about 295 lbs and (along with the optics) takes up to 16 ft^3.

The two optical sensors cannot be used simultaneously because they share the same optics. However, the mission planner can dynamically choose which sensor to use. It takes only five seconds to change from EO to IR or from IR to EO.

The Ground Systems

Global Hawk has two ground-based command-and-control elements: the MCE and LRE. The MCE provides operational command and control to the vehicle while it is on station, flies the vehicle as needed,

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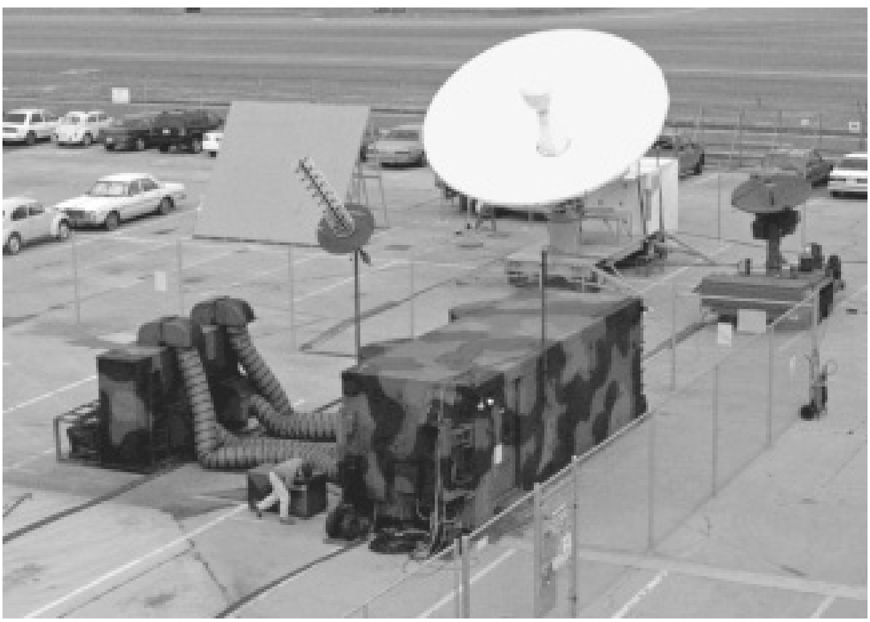
[5] The commonly used figure of merit for resolution—image quality—is the National Image Interpretability Rating Scales.

plans the mission, and acts as the central mission-data reception site. The LRE guides the vehicle to and from the forward airfield and flies the vehicle until the MCE takes over control. Both elements are contained in deployable trailers (see Figures A.4 and A.5). The elements also include a variety of antennas for communicating with the UAV (via satellite if a vehicle is BLOS) and with other ground locations, as well as an assortment of support equipment, including generators. Both elements were designed to be transported easily. For operations, they do not need to be collocated. The LRE element needs to be in the vicinity of the base at which the Global Hawk air vehicles are stationed. However, current planning includes an option for leaving the MCE in the continental United States (CONUS)—reachback—and using satellites and, if necessary, ground relay stations to transmit the

Figure A.4
Global Hawk's MCE



SOURCE: Nunn (2003), slide 15.

Figure A.5
Global Hawk's LRE

SOURCE: Nunn (2003), slide 15.

mission data directly to Global Hawk's main operating base and associated CONUS intelligence centers.

The equipment in the LRE includes a trailer, a power generator, an air conditioning unit, various antennas, and a differential Global Positioning System (GPS) unit. The trailer contains a pilot station (from which the operator can assist the vehicle in landing and takeoff) and mission-related displays. The displays are primarily for situational awareness. Since the LRE is designed to be rapidly deployable, all the required equipment will fit onto two pallets that fit within a C-130.

Both the MCE and LRE act as the vehicle's pilot; the MCE acts mainly when the vehicle is operational over an area of interest, and the LRE acts primarily when the vehicle is landing or taking off. The MCE uses BLOS communication links exclusively. This allows it to be located almost anywhere in the world. The present basing plan

calls for a main operating base in CONUS (Beale AFB, California) and three forward operating bases (one each in the Pacific, European, and Central commands).

The MCE controls the Global Hawk during most of the mission, typically taking control of the vehicle from the LRE at about 200 mi from the base. The MCE is actually able to control at least two air vehicles simultaneously, switching from one to the other as needed. The Global Hawk vehicle has a sophisticated autopilot, allowing it to "fly itself" on programmed flight paths without MCE interference for almost all the mission. Of course, mission needs change, and the autopilot is interrupted frequently. However, if Global Hawk is simply ingressing or egressing from its designated loiter location, little interruption is needed from the MCE. Thus, having two vehicles in the air simultaneously, with one flying to or from the loiter area, does not appear to be particularly difficult for the MCE to manage.

The MCE performs the following specific functions:

- plans the mission, using inputs from various organizations regarding the purpose of the mission, the intended targets of interest, and the status of enemy defenses
- plans and manages the communication links
- flies the airplane to and from the area of interest, assuming control from the LRE when the vehicle is (usually) about 200 mi from the launch location
- receives and records the data from the sensors, monitoring the images in real time
- transmits the received data to the IES for further evaluation and exploitation; the MCE has no responsibility for data exploitation at the site, although it receives and monitors the video feed from the EO/IR sensors
- monitors the status of the vehicle and the mission payload, takes corrective actions to keep both the vehicle and the payload operating as intended, and (if necessary) orders the vehicle to terminate the mission and return home

- plans and executes self-defense measures if the vehicle comes under threat of enemy hostile action
- is the focal point for interactions with various command, control, and communications outside of the Global Hawk operation.

The pilot may need to react quickly to unexpected deviations during takeoff or landing. If manual control is needed during landing or takeoff, it is important for the pilot (located in the LRE) to be in direct LOS communication with the air vehicle. Using an indirect satellite link would delay the pilot's response to changes in the vehicle's orientation enough to make remotely piloted landings and takeoffs highly risky for the safety of the vehicle. Therefore, the LRE needs LOS communication links and thus must be deployed near the vehicle's forward landing site.

The LRE performs the following specific functions:

- prepares the vehicle for launch by inserting the necessary encryption codes and other mission-rated data
- taxis the vehicle around the flight line (both before takeoff and after landing)
- launches the vehicle and flies it until handing it off to the MCE when the vehicle is about 200 mi from the vehicle's forward base
- recovers the vehicle after it has completed its mission, assuming control about 200 mi from the forward base.

The handoff from the LRE to the MCE occurs approximately 45 min into the flight, when Global Hawk has reached an altitude of approximately 50,000 ft. At this time, the vehicle begins a slow climb. As it burns fuel, getting lighter, the vehicle climbs to maximum altitude of approximately 60,000 ft. The vehicle is trimmed so that it flies a rising altitude profile rather than a constant altitude profile. This will change for the B model. See Figure A.6 for a sample Global Hawk mission profile. If the range from the takeoff point is 1,200 nmi (4 hrs) to the target area, Global Hawk will have approxi-

mately 20 hrs to loiter.[6] Increasing the range to the target area will decrease loiter time.

Operational Concept

The following subsections highlight elements of the basic and expanded CONOPs for Global Hawk (ACC, 2002; ACC, no date).

Tasks

The potential tasks for the Global Hawk system include providing the following:

- near-real-time targeting and precision strike support
- near-real-time combat assessment
- enemy order-of-battle information
- special operations
- blockade and quarantine enforcement
- sensitive reconnaissance operations
- humanitarian aid.

Basing

The system's main operating base will be Beale AFB, California, at which most associated activities other than forward deployment will be accomplished. There will be three forward-deployment bases (not specified) will be established, one each in the Central, Pacific, and European commands. These bases will host Global Hawk vehicles, their LREs, and (perhaps) also their MCEs. Support for Global Hawk operations will be based there as well.

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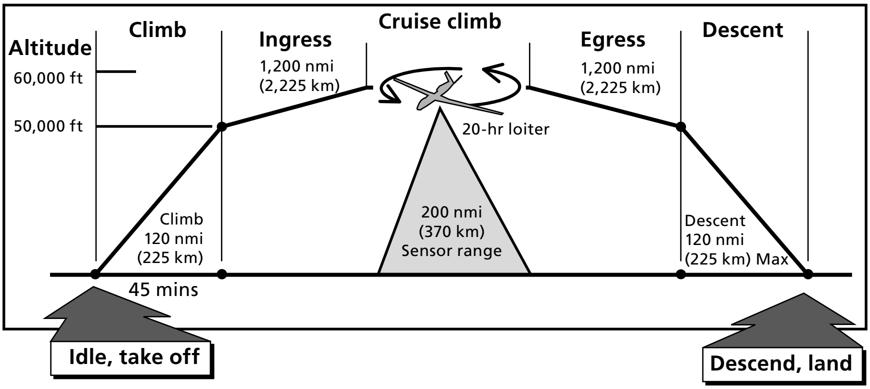
[6] Maximum endurance is 28 hrs; deducting 4 hrs for ingress and 4 hrs for egress yields 20 hrs for loiter.

Figure A.6
Sample Global Hawk Mission Profile



SOURCE: Nunn (2003), slide 20.
NOTE: The 200-nmi sensor range shown is the maximum for SAR. The maximum side-looking range of the EO/IR signature is substantially smaller.
RAND *MG350-A.6*

If necessary for operational reasons (for example, to base Global Hawk closer to targets of interest), additional forward bases will be used. In this case, Global Hawk vehicles and the needed LRE modules will be deployed to these bases temporarily.

Capabilities

Global Hawk will fly from its forward base to its designated operating location, establish a loitering pattern, and commence surveillance. The mission is preplanned, and the details of the flight path are fed to Global Hawk.[7] In general, Global Hawk will be given a set of waypoints and will fly from one to the next using its autopilot. Should something occur that would force Global Hawk to abort its mission, the autopilot would simply backtrack along the waypoints to its forward base.

To accomplish Global Hawk's primary mission (persistent surveillance of the specified target area), multiple vehicles will be used.

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[7] The mission plan can be changed in flight, should circumstances so dictate.

When the endurance capability of one vehicle has been depleted, another will take its place. To have continuous coverage, the second vehicle must be in the loiter area when the first vehicle departs. This requires launching the second vehicle from its base substantially before the first vehicle must leave the loiter area. Three vehicles are required for reasonable flyout ranges.

While on station, Global Hawk transmits its mission data to an MCE.

Force Structure

The Global Hawk's force structure is built to provide six simultaneous wartime orbits anywhere in the world (two at each forward operating location). It is expected that not all these orbits will require the same mission packages. Wartime coverage is assumed to require 30 days of continuous (24 hours per day) coverage. In peacetime, the anticipated mission capability needed is one strategic reconnaissance operation every other day. The specified mission capability suggests a primary mission aircraft inventory for Global Hawk of 18 air vehicles.

Reachback

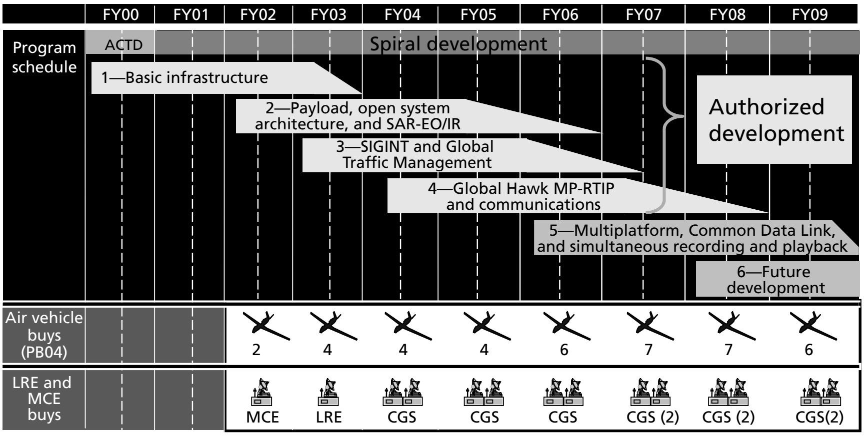
It was originally assumed that the MCE would be forward-deployed along with the vehicle and LRE. However, in Operation Iraqi Freedom, the Air Force pioneered a way to keep the MCE at its main operating base, Beale AFB, and still control the vehicle in the area of responsibility.

Being able to keep the MCE at a single location within CONUS has a number of advantages. Thus, the standard procedure for Global Hawk command, control, and communications has changed.

Acquisition Plan

Figure A.7 portrays Global Hawk's approved program plan, covering both the air vehicles and the ground stations. Note that the vehicles

Figure A.7
Global Hawk's Incremental Development



SOURCE: Adapted from Nunn (2003), slide 3.
NOTES: Based on FY04 President's Budget; an additional 11 buys occur after FY 2009.
One GCS consists of an LRE and an MCE
RAND *MG350-A.7*

and ground stations are bought in lots. The figure also shows how mission capability is added through spiral development. The vehicle lot buys and the spiral are not synchronized, leading to the possibility that there will be a fairly large number of different vehicle-and-payload options, which in turn will increase the complexity of providing adequate support for Global Hawk.

Global Hawk program development involves the following four sequences:

1. Incorporates the basic infrastructure available in FY 2001 into the RQ-4A. This includes the integrated sensor suite that encompasses the EO and IR optical sensors and the SAR. It also included dynamic replanning and retasking software. Because elements of the mission-related equipment used in the ACTD were obsolete, parts of the integrated sensor suite needed to be developed and acquired.

2. Includes enhancements to the SAR, primarily consisting of greater coverage for all radar modes (wide-area search, spotlight, and GMTI) and better resolution. Somewhat better resolution is expected from the EO/IR sensor.
3. Adds to the above an initial SIGINT capability, as well as an improved capability to interact with the global air traffic management systems. The latter is particularly important because Global Hawk must fly through U.S. and international airspace to reach its forward operating locations and its designated target areas. Without suitable approval by the international air traffic systems, such deployments would be greatly hindered. Fortunately, Global Hawk cruises at altitudes well above commercial aircraft, so deconfliction is primarily needed during takeoff, climbout, approach, and landing.
4. Significantly enhances the SAR, taking advantage of MP-RTIP. Enhancements to the optical sensors will also occur. At this stage in Global Hawk's evolution, the vehicles will be divided into those that carry the MP-RTIP radar and those that do not.[8]

When the SIGINT payload is added to the current imagery intelligence (IMINT) package, the program office describes it as "multi-INT." Initially, the SIGINT capabilities will be somewhat limited (but still very substantial). By FY 2007, the SIGINT payload will be expanded to include a highband subsystem. In FY 2009, the capability to collect airborne signals will be added. The MP-RTIP payload is a dedicated mission. Global Hawk will not carry either IMINT or SIGINT sensors.

Table A.2 shows the number of vehicles and associated ground elements acquired in each lot buy. Adding them up, the Air Force plans to acquire a total of 51 aircraft and 10 ground stations. The first seven will be RQ-4A (2,000 lbs payload capability). The remaining 44 will be the larger RQ-4B (3,000-lb payload capability). Table A.3 shows some of the performance goals expected of Global Hawk.

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[8] Spirals 3 and 4 are for the RQ-4B vehicles.

Table A.2
Global Hawk's Program

Unit	Buy Quantity
Air vehicles	
Primary mission aircraft inventory (PMAI)	18
Primary development and test aircraft inventory (PDAI)	4
Primary training aircraft inventory (PTAI)	2
Primary aircraft inventory (PAI)	24
Backup aircraft inventory (BAI)	4
Attrition reserve to replace PAI Losses	23
Total overall aircraft inventory (TOAI)	51
Common ground stations (MCE and LRE)	
Primary mission (supports 6 orbits)	6
Development and test	2
Training	2
Total CGSs	10

SOURCE: Nunn (2003), slide 37.

NOTE: CGS stands for *common ground station*.

Table A.3
Global Hawk Logistics and Readiness Thresholds

Performance Parameters	Threshold	Goal
Effective time on station rate (%)	90	95
Mission capable rate (%)	75	85
Mean time between critical failures (hrs)	100	160
Mean time between maintenance (hrs)	TBD	TBD
Mean repair time (hrs)	4	2

The effective time on station goal is 95 percent. The Air Force has set as their performance criterion that 95 percent of the time Global Hawk will be on station and operating, with a not-to-be-less-than 90 percent as a threshold. This effective time on station rate directly affects the number of vehicles needed at the forward operating location and is sensitive to the equipment's mean-time-between-failure rates and the vehicle's mean repair and turnaround time at the base.

APPENDIX B

Predator

This appendix describes some of the general characteristics of the Predator program. It will cover the program's history, a description of Predator's air vehicle and ground components, Predator's CONOP, and its acquisition plan. This appendix is not intended to be comprehensive but is structured to provide some of the details not provided in the main report.

System History

Predator is an offspring of an ACTD program run by DARPA. The purpose of the ACTD program was to demonstrate that an UAV could be built to fly 500 nmi from an operating airfield to a target area, remain on station for at least 24 hours, have a payload capacity of at least 400 to 500 lbs, and fly at an altitude between 15,000 and 25,000 ft—a Tier II UAV.[1] The ACTD was also to be used to verify the system's military utility. Because survivability at these altitudes was thought to be questionable (the UAV was not to be stealthy), the

[1] The ACTD's goal was to produce three high-altitude, long-endurance platforms—Tiers I, II, and III—each having different design objectives. The Tier I vehicle, the Gnat-750, focused on loitering at about 16,000 ft. The CONOP for Tier II MAE UAVs (the Predator) includes operating at altitudes no greater than 25,000 ft at airspeeds of 60 to 110 kts. Tier I and Tier II vehicles were not designed to be stealthy. the Tier III vehicle, DarkStar, was designed to fly above 40,000 ft and to be highly stealthy.

unit cost of the vehicle had to be such that it could be viewed as expendable. The resulting unit cost cap was set at $5 million.

Predator was first used in an operational context in Bosnia in July 1995, where it proved its operational utility. The resulting enthusiasm for rapidly fielding Predator led to a decision to forgo the normal acquisition approach and simply make modifications to the vehicle as technology and money allowed. As a result, many of the normal activities associated with formal engineering development activity (now called SDD) did not occur. Among these, and of specific interest to this study, were the lack of data, tools, and planning for long-term support of Predator. Moreover, the resulting financing did not allow the Air Force to redress some of these shortfalls, in part because the original cost cap was still in place.

Predator has been successfully used in nearly every conflict that has occurred since the mid-1990s. It played prominent roles in Afghanistan and in Iraq, with lesser roles elsewhere (for example, Somalia). While the Air Force is its largest user, Predator has been sold to other U.S. government clients as well. At the time of this writing, over 100 Predators have been built, and General Atomics (the prime manufacturer) is producing them at a rate of approximately 12 per year.

The Predator System

The Predator system consists of three elements—the air vehicle, the GCS, and the ground-based mission command and control station (CS). In this section we will discuss the air vehicle and its various parts and associated mission payload packages for both Predator A (MQ-1) and Predator B (MQ-9). The GCS, which helps land and takeoff the air vehicle, is where the mission pilot is housed. The ground-based mission command and control station oversees the mission plan and its implementation, makes command decisions when needed, collects and disseminates the mission data, and interacts with higher Air Force echelons. We discuss each of these elements below.

Predator—The Air Vehicles

Some of the characteristics of the two Predator vehicles are listed in Table B.1. Predator A (see Figure B.1) weighs about 2,250 lbs, has a wingspan of about 49 ft, and is powered by an internal-combustion engine adapted from a snowmobile motor. Its operating characteristics come close to meeting the requirements of the DARPA UAV ACTD. It can meet the 24-hour endurance requirement without external stores, can fly up to 25,000 ft, and has unit cost under $5 million.

Predator A's relatively slow cruise speed hinders its ability to operate from a base that is more than 500 nmi from the desired target area. But its simple operation allows it to operate off very austere bases, enabling a reasonable number of basing options that are within flying range. The vehicle and all of its parts are designed to be easily transported in a C-130, which also can fly into and out of austere bases.

Table B.1
Predator A and Predator B Characteristics

	MQ-1 (Predator A)	MQ-9 (Predator B)
Approximate weight (lbs)	2,250	10,000
Speed at altitude (kts)		
Loiter	70	200
Maximum	120	220
Wingspan (ft)	48.7	64.0
Maximum payload (lbs)		
Internal	450	750
External	200	3,000
Approximate ceiling (ft)	25,000	45,000
Endurance on station (hrs)	24[a] 12[c]	24[b]
Propulsion	Propeller, modified snowmobile engine	Small turboprop engine
Sensor and weapons carried	EO/IR plus two Hellfires or SAR	EO/IR plus SAR or four 500-lb PGMs

SOURCE: Office of the Secretary of Defense (2002); Air Force (2001), and Federation of American Scientists (2002).
[a]Not carrying weapons.
[b]Carrying some weapons.
[c]Carrying two Hellfire missiles.

Predator B (see Figure B.2) was developed in response to some of the limiting factors found in Predator A. The operational ceiling was raised to 45,000 ft to place Predator B above most of the bad weather conditions that plague Predator A. (Predator A's wings are subjected to icing conditions, a relatively common occurrence at its medium altitude.) Moreover, raising the ceiling also put Predator B above the operational capabilities of many of the highly proliferated SAMs found in many parts of the Third World. Increasing the air vehicle's speed shortened the transit times between the operating base and desired orbiting location, allowing forward bases to be located farther from the target area, thereby increasing its security from both detection and attack. Making the vehicle larger allowed Predator B to carry a wider range of mission payloads, including a greater number and variety of bombs, and more advanced electronic payloads. With greater payload capacity and better survivability characteristics, the cost ceiling was raised.

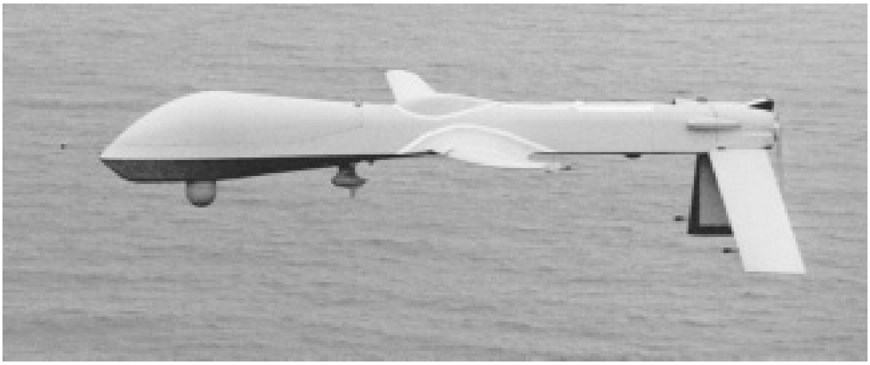
Predator B is now being introduced into the force. It is noteworthy that its introduction has not diminished the desire to continue to acquire and field Predator A.

Figure B.2 is a picture of Predator B (MQ-9). Note that its shape is nearly the same as Predator A's, except for the tail section, where an additional surface was added to maintain vehicle stability. The landing gear was also modified and strengthened. The major differences are mostly internal. Predator B carries a larger payload, thus enabling an expanded set of additional mission modules.

In Predator A, the use of a power plant taken from a snowmobile limited the electrical power that could be taken from the engine, which in turn, limited the equipment that Predator A could employ while in flight. The power plant, plus propeller, also limited the vehicle's speed and altitude capabilities. Because of the limited power and lifting surfaces, hanging external ordinance on Predator A forced the off-loading of fuel, reducing its orbit time on station.

Predator B has gone to a turboprop engine, providing substantially more electrical power for the vehicle's payload and increasing its

Figure B.1
Predator A (MQ-1) in Flight



SOURCE: Federation of American Scientists (2002).

Figure B.2
Predator B (MQ-9) in Flight

SOURCE: National Aeronautics and Space Administration Photo Collection (ED02-0185-01).

transit speed. The enhanced speed allows the forward operating location to be farther from the target area of interest without sacrificing time on station.

Because of the altitude limits, Predator A has to deal with weather (especially icing conditions) that can cause catastrophic results (such as loss of the vehicle). Modifications to the wing and the vehicle to address icing concerns lower the vehicle's on-station endurance through a loss of lift from the wing and the added weight of the de-icing equipment. Predator B's turboprop engine gives it the capability to fly substantially above the weather, avoiding dangerous weather conditions when it is on station.

The Ground Stations

Predator has both a forward-based GCS and a mission control station (CS). Originally, the GCS was housed in a large 40-ft trailer. However, it was determined that all that is needed at the remote forward location are the pilot stations. The trailer was abandoned, leaving a much smaller enclosure with just the pilot workstations. The ancillary equipment (for example, power generator) were also reduced in size, and the number of people located forward—the pilots and the personnel needed to support the vehicles and the GCS—became minimal. The GCS is designed to be readily deployable to austere sites that have little or no supporting infrastructure. Thus, it has been designed to be minimal in its capabilities and support needs, and is sufficiently small to permit deployment by small transport aircraft capable of landing at austere locations.

The GCS plays a direct role in landings and takeoffs of the air vehicle and passes instructions to the vehicle while it is in flight. The GCS consists of two pilot stations, each with a joystick for piloting the vehicle, and a couple of displays that show the vehicle's status and flight-related data essential for successfully piloting the air vehicle.

The GCS also has a direct LOS communication antenna and a larger antenna for communication to the vehicle via satellite relay. The LOS communications link is essential for piloting the vehicle when it is landing or taking off. Sending vehicle flight data to the GCS by means of a satellite relay would add a delay into the pilot's reaction time insufficient to make corrective maneuver instructions to save the vehicle under a number of realistic scenarios.

The BLOS communication link allows the GCS to fly the vehicle when it is performing it mission functions. The sensitivity of time delay on successfully flying the air vehicle is much less if the vehicle is at altitude. The pilot has substantial time to detect the problem and make the corrective control instructions. The GCS also has a deployable differential GPS unit for providing precision landing data to Predator and the GCS.

The mission CS is considerably larger. It consists of a large 40-foot trailer, a power generator, an air-conditioning unit, and a set of antennas (one being a 6-m antenna that receives the video data from the Predator). The CS performs the following essential functions:

- mission planning
- control and management of the mission
- reception of Predator's mission data and disseminating it to the appropriate data exploitation organizations
- interacting with other organizations, including higher commands
- making all decisions related to supporting the operation, except those actions taken at the forward site.

Since the CS interacts with the vehicle while the vehicle is on station using BLOS communication links that require satellite relay, the location of the CS is flexible. It could be collocated with the GCS, assuming that the forward deployment location has sufficient indigenous support assets (this is often not the case). It could be located at a different base in the theater of interest or even in CONUS. CONUS basing is currently the preferred option. And, in the future, it could be located in a mobile platform, assuring maximum flexibility.[2]

The CS needs external inputs to aid in situational awareness. These include information on target areas of interest from warfighting commanders and potential dangerous areas where Predator might come under attack. When Predator is on station, targets of opportu-

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[2] One example of a mobile platform would be the Joint Surveillance Target Attack Radar System.

nity may arise, causing changes in Predator's mission plan. These may be handled exclusively by the CS or could involve consultation and coordination with the upper command echelons.

Operational Concept

In this section, we will address Predator's CONOP in conflict situations. We first discuss Predator's mission. Then, we will discuss Predator's deployment to locations outside the United States, its employment over potentially hostile territory, and its command and control structure.

Mission

Originally, Predator was only viewed as a medium altitude ISR platform. The vehicle's size, payload capacity, endurance, and maximum altitude were all aimed at gaining high-quality imagery from targets on the ground (both stationary and moving). Once the target is found, then Predator could provide suitable location information (and even employ laser designator when useful) to permit armed manned aircraft to fly to the target location and attack.[3]

This reconnaissance-strike mission, using both UAVs and manned aircraft, worked reasonably well. But there were times when the manned aircraft simply were not positioned to arrive in time for a successful strike. The inherent flexibility of Predator encouraged planners to think about expanding Predator's basic mission into one involving a strike capability. Thus, the Predator A was modified so that it could carry two Hellfire missiles under its wings and use its target designator capability to guide the missiles to their target. This also worked well. However, the resulting drag from the missiles, coupled with the needed changes to Predator to carry the missiles, resulted in a loss in aerodynamic quality. Moreover, maximum gross takeoff weight limits required Predator to carry less fuel, with the

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[3] Before Predator was outfitted to carry weapons, this was the only option for prosecuting detected targets. Predator has been used in this role in many of the recent conflicts.

total result being a loiter time significantly less than 24 hours. Partly in response to this, but also consistent with the natural growth in Predator's future missions, a new version of Predator (MQ-9) has been developed and is in production.

Arming Predator is not a complete substitute for manned strike aircraft (fighters or bombers), but a recognition that occasionally a high-priority, time-sensitive target will emerge in Predator's field of view and that, under these circumstances, an armed Predator is an excellent option. The full range of potential missions is evolving. Potential missions include the following:

- expanded intelligence collection, for example, SIGINT
- enhanced time-sensitive targeting
- tactical communications rely node
- suppression of enemy air defenses support (both locating and attacking)
- close air support
- search and rescue.

These potential missions suggest that Predator will have a fairly large number of payloads and weapons associated with its operational deployment. With the introduction of the new, larger MQ-9 Predator, further adaptation of Predator is likely.

Deployment

Predator is routinely deployed from the United States to a forward location to perform its mission. Predator's main CONUS home base is Indian Springs Air Force Station, Nevada. The entire deployment package consists of the air vehicles; the GCS (and perhaps the CS); various ground-based antennas for communications to and from the air vehicle and between the GCS and CS; equipment for a differential GPS at the site; maintenance equipment (including spare parts); and personnel to operate the air vehicle, maintain it, and manage the base (for example, prepare food and provide security).

For deployment, Predator's wings are removed and the entire vehicle is put into a box for transporting to the desired location. Assembling or disassembling Predator's wings is simple, involving the

removal of two connectors that hold the wings in place after they have been inserted into the fuselage. Because of the different missions that Predator performs, and the potential for encountering icing conditions, each vehicle has multiple wings (for example, with and without weapon attachments, with and without de-icing capabilities). These wing kits give the mission planner the widest set of options for employing Predator's capabilities.

The entire deployment package is airlifted to its planned forward operating location. The deployment package consists of two pallets that fit within a single C-130. The total size of the deployment might vary, with four air vehicle sets being the nominal for continuous operation (three to provide continuous coverage and a fourth as a spare in case of a vehicle loss). Planning calls for no more than 24 hours for deployment preparation and 24 hours to achieve active status once reaching the deployment site.

The deployment site is usually a remote site, away from any major air base, and is, at best, sparsely provisioned. Predator deployment means bringing essentially everything that it requires for 30 days of operation. Moreover, Predator relies almost exclusively on continuing airlift support during the employment phase, as access to suitable ground transportation is not always possible.

Mission Preparation. Every Predator must have a flight plan to perform its mission. The flight plan is a natural outgrowth of an overall mission plan, where the target area has been specified, the purpose of the flight defined, the timing and number of sorties identified, and the communication links established (for both vehicle monitoring/control and mission data transmission). Higher command echelons provide the elements of the overall mission plan to the Predator CS staff, but the CS staff is responsible for building the flight plan and transmitting it to the remote site for insertion into the air vehicle. The flight plan is inserted into the vehicle's computer using waypoints that tell the vehicle where to fly.

Once the mission plan and the weather conditions are known, Predator is configured to perform the mission, accommodating weather factors specific to the flight plan and the weather that day. For example, if the mission called for locating and attacking specific

time-sensitive targets, Predator would replace the long-endurance wings used for persistent surveillance with wings configured to carry missiles. Similarly, if icing conditions were anticipated in Predator's loitering area, then wings with de-icing capabilities would be used. The de-icing wings are not as efficient as the long-endurance wings and therefore are not used unless the danger of icing conditions merits the reduction in loitering time.

Once Predator is deployed, it may be called on to perform a variety of missions. The selection of a specific mission kit is driven by the mission plan and the environmental conditions anticipated. The time required to change both the wings and the mission payload is only a few hours. Table B.2 shows a notional set of mission kits that can be made available for a Predator A air vehicle. There are five different missions shown and two environmental conditions (with or without the threat of icing while in flight).[4]

The air vehicle is fueled before each flight. When the air vehicle is flight-ready, its mission parameters are electronically fed into the vehicle's flight computer. These parameters include both a flight plan and instructions on the use of the mission payload.

Predator Takeoff and Landing. The pilot in the GCS is responsible for managing the air vehicle throughout its flight, as well as when it is taxiing on the airstrip, taking off, or landing. The GCS is in direct communication with the vehicle by an LOS communication link while the UAV is taking off, landing, or flying near its operating base. Pilot response times and their importance in taking corrective actions if the vehicle gets into trouble while landing or taking off drives the requirement for locating the GCS at the forward operating location.

For takeoff, the pilot first taxies Predator into position and then executes the takeoff. Predator has a small camera in its nose that allows the pilot to look forward and keep the air vehicle straight on the runway. The display panels at the pilot's workstation also show

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[4] The five missions shown in Figure B.3 are representative but neither complete nor necessarily going to occur.

Table B.2
Notional MQ-1 Mission Kits

Kit Number	Missions	Attributes
1	ISR	EO/IR ball Endurance wing
2	ISR Anti-ice	EO/IR ball SAR Anti-icing wing Anti-ice collar
3	Forward air controller, airborne	MTS Boresight unit Endurance wing
4	Forward air controller, airborne Anti-ice	MTS Boresight unit Anti-icing wing Anti-ice collar
5	Air interdiction Forward air controller, airborne	MTS Weapon wing Two AGM 114 pylons
6	Self-protection ISR Counter-air	EO/IR ball Weapon wing Four Stinger pylons
7	Self-protection Forward air controller, airborne Air interdiction	MTS Boresight unit Weapon wing Four Stinger pylons
8	Multirole	MTS Boresight unit Weapon wing Two Stinger pylons One AGM 114 pylon

data on the aircraft's status (for example, speed).[5] Once safely airborne, the vehicle can fly itself to the target area, following a set of waypoints that were inserted in the air vehicle's computer as part of the mission plan. Landing is just the reverse of takeoff.

Predator can be subject to overheating if it is left standing in the sun on extremely hot days. If overheated, some of the air vehicle's electronic components may not function. The remote sites are not

[5] At the time of this writing, the displays are not configured to look like displays commonly found in most manned aircraft.

likely to have hangars that would protect Predator from becoming overheated.

Predator's landing and takeoff capabilities are augmented by a differential GPS unit that is deployed around the airfield at the start of the operation. Because of Predator's high-lift wings, it cannot safely take off or land at remote airports if the crosswinds exceed approximately 20 kts.

Predator's lack of a high data storage capacity makes it nonoperational if it cannot transmit data back to the CS. Thus, with loss of communications, there is no reason to leave the vehicle in the target area. If communication links to Predator are lost, the vehicle is programmed to return to the operating base following the same route that it took from the forward operating base to the loitering area and orbit above the original launch site until communications can be restored or fuel is exhausted. The existence of several redundant LOS communication antenna on the air vehicle (including one in the VHF band) makes it highly likely that the GCS will be able to regain communications with the vehicle and land it safely.

Employment

The original motivation for the Predator ACTD was the potential for achieving persistent surveillance and reconnaissance over an area of interest. None of the then-current U.S. intelligence platforms could provide any degree of persistence, leaving holes in intelligence coverage that knowledgeable antagonists could (and did) exploit. Thus, the first Predator—at that time labeled RQ-1, where the R stood for reconnaissance—was dedicated to the ISR mission, with a mission payload consisting of an EO/IR sensor ball and a SAR.

The ISR mission calls for Predator to loiter for up to 24 hours at the desired target area (the actual location of Predator can be changed during the mission to respond to new information and/or new collection opportunities not known when the mission was planned). The data, collected by the sensors, is immediately sent back to the CS for further analysis. The EO/IR signal is similar to a video signal and is not encrypted. If listening to the appropriate frequency, Predator's signal can be displayed on a television and viewers can see, in near

real time, the images that are being sent for exploitation. Demonstrations of the video feed to Air Force leaders when Predator was flown in Bosnia captivated them and added to the enthusiasm for acquiring more Predators as well as transforming Predator into an armed surveillance platform capable of time-sensitive targeting missions.

One pilot can in principal manage multiple Predator vehicles. Predator usually operates under instructions from its preprogrammed autopilot. The autopilot is given a preplanned mission routing and payload employment plan prior to its departure from the forward base. The pilot can assume control of a vehicle whenever he wishes, but the vehicle will proceed with its preplanned mission (or updated planned mission) if it receives no instructions to do otherwise. By taking advantage of this, the pilot can fly one vehicle and simply monitor the other vehicles to ensure that they are doing what is expected.

When Predator discovered time-sensitive targets in Bosnia, the Air Force attempted to vector strike aircraft to the target for strike. However, the delay between the target discovery and the arrival of the attacking aircraft was often too long for a successful strike. Assigning a fighter to loiter in the vicinity of the Predator so that strikes could be more successful was an inefficient use of a valuable Air Force asset. In the Air Force's view, it would be far more effective to arm Predator and have it perform both the ISR and strike mission.

The Predator must first detect, locate, and identify the desired target before attacking it. This part of the mission is more or less identical in it mission parameters as the persistence ISR mission. However, once a time-sensitive target has been identified and an attack against it authorized, Predator uses its laser designator to illuminate the target and launches a Hellfire missile to attack it.[6] The CS controls the authorization for releasing the weapon, based on conditions from higher authorities.

At least in part because Predator is essentially hand-built, it has proven to be easily modified. Adding a Hellfire missile to its wings

[6] Hellfire has a laser seeker. The seeker locks onto the illuminated target, and the missile guides itself to the laser spot until it hits it.

was quickly accomplished, along with suitable software for weapon employment. A laser designator was added to the mission ball, along with a laser tracker and the ability to track moving targets. Hence, the RQ-1 designator was modified to be MQ-1, where M stands for multimission (both ISR and strike). MQ-1 can carry up to two Hellfire; MQ-9 can carry up to 10 Hellfire and can also carry different weapons (limited by total weight and onboard software to target it).

Predator was not built to avoid detection. No attempt was made to make it stealthy, although its shape and its relatively small size make it difficult to see by the naked eye. Predator has also made no plans to use some of its payload for self-defense purposes. It carries no electronic countermeasures equipment and no decoys. It is admittedly vulnerable to direct attack by SAMs if its altitude is relatively low, and to air-to-air missile attack as well. As already noted, its unit price was capped at a level that would allow Predator to be considered expendable.

So, to nobody's surprise, Predator A has been lost in combat. But to almost everyone's surprise, the losses have been far less than anticipated. Although not designed to be stealthy, Predator inherently has a small radar cross-section and radiates a very low IR signature. Experience in Bosnia, Afghanistan, and Iraq has showed it to be a difficult target for most SAMs found in the Third World. Sophisticated SAMs, similar to those being built by the U.S. and European allies, would find Predator an easy target, but fortunately, to date, the UAV has not had to face such threats.

The primary survivability measure available to Predator A is avoidance. This tactic requires good intelligence on the vehicle's location and flexible mission planning that achieves safe routes to and from the target area of interest. Predator can also fly at altitudes where most IR SAM threats have poor performance and where ground-to-air artillery threats are minimal. Nevertheless, it is expected that modern SAMs will eventually be acquired by countries hostile to the United States (including those in the Third World). When this happens, Predator A will face higher attrition rates. This will negatively affect the number of the Predator As needed to perform the mission.

Predator B was designed to be less vulnerable than Predator A. It achieves lower vulnerability by flying higher, and because of its altitude, can loiter further from the target area it is surveying. Because of its greater payload capacity and the greater available electrical power, defensive suites of some form could be added to Predator B in the future, should the threat materialize.

Acquisition

General Atomics has already built over 100 Predators and is continuing to build both Predator A and Predator B at a rate of 12 per year. The Air Force is expected to be the recipient of half of these vehicles.[7] General Atomics is seeking to expand the number of Predators it sells per year, seeking new clients (for example, the Navy, the Department of Homeland Security, and selected friendly countries).[8] During Operation Iraqi Freedom, production surged to a rate of 24 per year. However, given the labor-intensive way that the vehicle is built, such a surge would be difficult to maintain without investment in facilities and an increase in the labor force.

The Air Force is planning to maintain a force of 11 Predator A systems (8 combat coded and 3 training coded). A system consists of 4 Predator vehicles, one CS, one GCS, and all the associated personnel and equipment needed to employ the system. Given the additional missions that the Air Force is considering, it is quite possible that this number will grow. At this time, it is hard to know just what Predator's future portends, but its success and the enthusiasm for its capabilities elsewhere in the Government suggests that the above force size could easily grow.

Predator is cheap by most military system standards. A fully outfitted Predator A vehicle costs just under $5 million, corresponding

[7] The remainder are being acquired by other U.S. Government clients.

[8] General Atomics is also heavily involved in the development of at least one new UAV for the U.S. Government.

to an Air Force self-imposed maximum cost of $5 million for any vehicle that will be considered expendable. The costs are as follows:

- fully loaded vehicle without mission payload: $1.8 million
- vehicle with mission payload: $4.8 million.

Predator B at $10 million each is not expendable—at least by the Air Force's stated standard. Its ability to fly higher and faster improves its survivability over Predator A. However, its main advantage over Predator A is its greater payload capacity and better endurance when outfitted with external weapons.

APPENDIX C
Small UAVS

Small UAVs, that weigh less than 100 lbs, have long been of interest to model-plane builders and others. However, the emergence of microelectronics has opened that interest to the potential utility of such vehicles for military applications. It is thus not surprising that the UAV community has either built or is proposing to build literally dozens of such vehicles, each with somewhat different design and performance parameters.[1] There are at least an equal number of such vehicles being built in other countries. It is worth noting that the simplicity of these vehicles, their relatively low unit costs, and the ease of their operation portend widespread proliferation around the world.

This appendix will focus its comments on only four UAVs:

- BATCAM
- FPASS, also known as Desert Hawk
- Pointer
- Raven.

We will briefly describe these four vehicles, what they do, and how they are controlled.

[1] See Appendix D for a listing of UAVs that are being built, acquired, or developed within the United States.

A Description of Four Small Air Force UAVs

Table C.1 lists some the physical characteristics of these four small UAVs.

First, each of these UAVs weighs less than 10 lbs. Their size is correspondingly small. They are all either hand-launched or launched using a simple spring-loaded device, fly at about 500 ft for about 1 hour, and are recovered, refueled (or recharged if using batteries), and reused. Their unit costs are relatively low, dominated by the sophisticated flight electronics and their optics payloads.

The mission for each of these UAVs is similar, although not identical. In general, they scout the terrain around the launch site, looking for potential enemy activities of interest.

In the case of FPASS (see Figure C.1), the vehicle flies around the periphery of an Air Force base looking for indications of potential hostile actions that might threaten the airfield. Its function is surveillance. It is flown both during the day and at night. As it is part of the air base's defensive posture, it is owned and operated by ACC.

BATCAM's function (see Figure C.2), in contrast, is reconnaissance. Owned and operated by AFSOC, the Air Force component that supports U.S. Special Operations Command, its role is to look over the next hill, alerting the special operations team as to what to

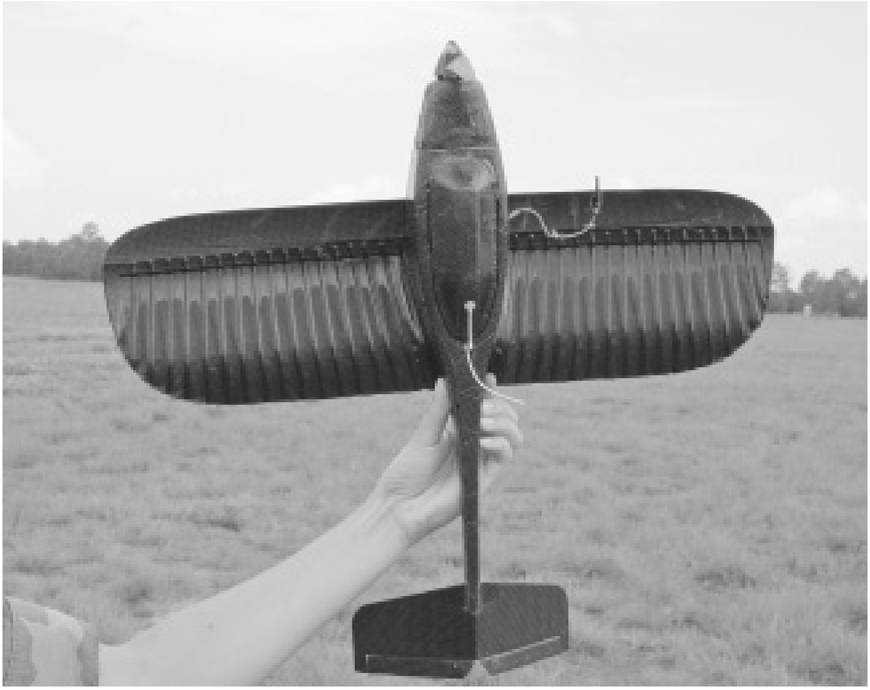
Table C.1
Size, Weight, Cost, and Performance Characteristics of Four Small Air Force UAVs

	FPASS	BATCAM	Pointer	Raven
Weight (lbs)	1.5	7.0	8.3	3.8
Dimensions				
Wingspan (ft)	1.9	4.3	9.0	4.5
Length (ft)	0.9	3.0	6.0	3.0
Performance				
Endurance (hrs)	0.5	1.0	2.0	1.5
Ceiling (ft)	500	500	500	500
Speed (kts)	35	42	88	52
Unit cost ($000s)	TBD	50	66	69

Figure C.1
FPASS

SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

Figure C.2
BATCAM



SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

expect. We are not aware of the payloads that it might carry, but presumably it also has optical sensor, both EO and IR.

The mission of Pointer and Raven is surveillance. Both Pointer and Raven provide real-time actionable information directly to the warfighter/operator. The data are not fed through a separate intelligence analysis, as with other UAVs. Figure C.3 is a picture of Pointer. Figure C.4 is a picture of Raven.

Figure C.3
Pointer

SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

Operating the Small UAVs

The operating system for each of these small UAVs is also similar. The control station consists mainly of a portable laptop computer, a small power generator, and a simple antenna. The laptop computer is used for all mission functions, including mission planning, vehicle control while in flight, and data collection and display. Figure C.5 shows BATCAM's ground control unit. Figure C.6 shows, more generally, all the components that make up BATCAM's system. Figure C.7 shows the ground control unit for Pointer.

The small UAVs are hand-flown. The pilot enters commands into the laptop computer, using the display to track the flight path of

Figure C.4
Raven

SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

the vehicle. A normal mission system includes two monitors, the second acting as a backup.

Small UAV Acquisition Plans

Pointer, Raven, and FPASS are all operational systems. The Air Force has procured the following:

- Pointer: 32 air vehicles and 16 ground stations
- Raven: 84 air vehicles and 41 ground stations
- FPASS: 126 air vehicles and 18 ground stations.

BATCAM is still under development, in the testing phase. The Air Force plans to procure 46 air vehicles and 23 ground stations.[2]

[2] Data from AFSOC/XPTU, February 1, 2005.

Figure C.5
BATCAM's Ground Control Unit

SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

Figure C.6
The BATCAM System

SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

Figure C.7
Pointer Ground Control Unit

SOURCE: Photo courtesy of U.S. Air Force Special Operations Command.

APPENDIX D
Comparison of UAVs

In this appendix, we show UAVs currently being built (see Table D.1) and those being developed in the United States (see Table D.2).

Table D.1
Production Vehicles: UAVs Being Built in the United States

Model	In Map[a]	Lead[b]	MTOW (lbs)	Max. Payload (lbs)	Dimensions: Wingspan (ft)	Dimensions: Length (ft)	Performance: Endurance (hrs)	Performance: Ceiling (ft)	Performance: Speed (kts)	Uses
Altair			6,985	660	86.5	36.2	>30	52,000		Scientific research
Altus			2,145	330	55.3	22.1	>24		115	Commercial
Backpack UAV			12	2		3.3	3	5,000	35	ISR, communications relay
Dragon Drone	Yes	USMC	90	15	8.2	5.3	2	10,000	80	EW, ISR, communications relay
Hellfox			350	130	9.7	11.2	8	19,000	120	EO/IR
Hunter	Yes	USA	1,600	200	29.2	23.0	12	15,000	110	EO/IR
I-Gnat			1,547	200	36.0	21.1	52	23,430	140	ISR+
Javelin			20	3	8.0	6.0	2	1,000	65	Reconnaissance
Mini-Vanguard			100	40	7.1	6.7	3	15,000	100	Reconnaissance
Neptune	Yes	USN	80	20	7.0	6.0	4	8,000	85	Reconnaissance
Perseus B			2,420	330	71.9	25.1	24	65,000		Scientific research, relay
Pioneer	Yes	USN	452	75	17.0	14.0	5	15,000	95	ISR
Pointer	Yes	USN	8	2	9.0	6.0	2	500	50	Reconnaissance, chemical detection
Predator (MQ-1)	Yes	USAF	2,250	450	48.7	28.7	40[c]	25,000		ISR and strike
Predator (9)	Yes	USAF	10,000	3,000	64.0	36.2	32[c]	45,000	225	ISR and strike
Prowler II			449	100	24.1	14.0	18	20,117	125	ISR and communications
SeaScan			34	9	9.6	4.0	>15	16,500	63	Sea surveillance
Sentry			250	65	11.0	8.0	>6	10,000	95	Tactical surveillance and relay
Shadow 200	Yes	USA	327	60	12.8	11.2	4	15,000	75	Reconnaissance

Table D.1—Continued

Model	In Map[a]	Lead[b]	MTOW (lbs)	Max. Payload (lbs)	Dimensions		Performance			Uses
					Wingspan (ft)	Length (ft)	Endurance (hrs)	Ceiling (ft)	Speed (kts)	
Shadow 400			447	66	17.0	12.6	5	12,068	75	Reconnaissance
Shadow 600			585	100	22.5	15.5	14	17,097	85	Reconnaissance
SkyEye			780	135	20.0	13.4	8	15,000	90	Surveillance
Spectre II			320	80	10.5	9.0	>5	13,000	80	Tactical reconnaissance
Tern			75	30	10.2	8.3	3		80	Airborne chemical sensor

SOURCE: The data in this table were gleaned from Shepard (2004) and may differ slightly from other sources sited in this document. For convenience, some values have also been rounded.

[a] Is the model in the DoD UAV roadmap?

[b] Lead organization or service.

[c] Clean.

Table D.2
UAVs Under Development in the United States

Model	Lead[b]	MTOW (lbs)	Max. Payload (lbs)	Dimensions: Wingspan (ft)	Dimensions: Length (ft)	Performance: Endurance (hrs)	Performance: Ceiling (ft)	Performance: Speed (kts)	Uses
UAVs									
BMQ-145 Mr		2,160.00	355.000	10.5	18.3		40,000		Medium-range reconnaissance
Buster		12.00	2.000	4.0	3.3	4	10,000	35.0	ISR
D-1		77.00	22.000	10.9	5.8	17			Atmospheric science, survey
Dakota		396.00	64.000	15.0		2+			Multimission
Global Hawk[a]	USAF	26,750.00	1,950.000	116.2	44.4	32	65,000		ISR
Helios		1,650.00		247.0	12.0		100,000	25.0	Environmental monitoring
Inventus "E"		5.00	6.000	5.9				25.2	Reconnaissance, remote delivery
Inventus S-1			50.000	10.6			10,000	58.8	Reconnaissance, remote delivery
Isis		426.00	75.000	24.0	14.7	24	15,000	100.0	Multimission
MUTS		77.00	33.000	11.9	5.9	1	6,500	60.0	Air-launched mini-UAV
PCUAV		40.00	11.000	19.8					MIT/Draper Labs R&D
Pathfinder Plus		748.00	100.000	11.9	119.8	15	65,000	20.0	Technology development
Predator B-ER		10,479.00	2,994.000	86.5	36.2	49+	52,000		DHS and Navy surveillance
Proteus		12,500.00		77.7	56.3	18	65,000		Multiple
Puma		12.00	2.000	9.0	6.0	4	150	60.0	RS
Sentry HP		325.00	75.000	12.8	11.0	6+	10,000	100.0	Tactical reconnaissance
SLURS		8.00		6.6	3.3	1	650	60.0	Short-range reconnaissance
Theseus		7,900.00		117.0	30.0	32+	65,000		High-altitude missions
Vindicator		800.00	200.000	23.4	15.8	12	30,000	80.0	Medium-range surveillance
Micro-UAVs									
Bat-3		20.00		5.00	4.50	6.00			Short-range surveillance
BATCAM		5.00		1.80	0.90	0.70	500	35.0	Close-range reconnaissance
Black Widow		0.12	0.033	0.75	0.75		200	30.0	

Table D.2—Continued

Model	Lead[b]	MTOW (lbs)	Max. Payload (lbs)	Dimensions: Wingspan (ft)	Dimensions: Length (ft)	Performance: Endurance (hrs)	Performance: Ceiling (ft)	Performance: Speed (kts)	Uses
Dragon Eye[a]	USMC	4.50	1.000	3.80	2.40	1.00	1,000	40.0	Small unit surveillance
Finder[a]	DTRA	59.00	13.500	8.60	5.30	10.00	15,000	65.0	Chemical detection
FPASS[a]	USAF	5.00	1.000	4.30	3.00	1.50	500	50.0	Base protection
Gator 1		0.22		0.63	0.63			25.0	R&D
Microstar		0.30		0.50	0.50	0.20	300	25.0	Surveillance
Silver Fox		20.00	4.000	8.00		4.00			Surveillance
Wasp		8.60		4.00	2.50	1.00	4,000	80.0	Gun-launched surveillance
X-UAV		95.00	20.000	6.70	3.80	1.50	15,000	160.0	Sensor platform
UCAVs									
X-45C[a]	USAF	35,000.00	4,500.000	48.00	36.00	>2.00	40,000	600.0	
X-47A[a]		5,500.00		28.00	28.00				ATD
X-46	USN	29,000.00	5,500.000	50.00	34.00	12.00	40,000		Multimission
Lethal UAVs									
LOCAAS		85.00	17.000	3.90	2.60	0.50	750	200.0	Munition platform
LEWK[a]	USAF?	800.00	200.000	15.00	10.00	8.00	15,000		ACTD demonstration SEAD
SilentEyes 115[a]	USAF	10.00	5.000	2.30	1.60	0.33	25,000[c]	80.0	Surveillance, BDA, etc.
Raven		4.40	0.400	4.50	3.00	1.50	500	50.0	Reconnaissance

SOURCE: The data in this table were gleaned from the Shepard Group (2004) and may differ slightly from other sources sited in this document. For convenience, some values have also been rounded.

[a]Is the model in the DoD UAV roadmap?

[b]Lead organization or service.

[c]Released at this altitude; glides to ground.

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[1] Now known as the Government Accountability Office.